ARQUEOLOGÍA COMPUTACIONAL

Nuevos enfoques para la documentación, análisis y difusión del patrimonio cultural

Diego Jiménez-Badillo (editor)

Arqueología computacional

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análisis y difusión del patrimonio cultural

Cultura digital

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del Patrimonio Cultural, financiada mediante el Programa Redes Temáticas
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Secretaría de Cultura
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Índice

MAAYA
Multimedia methods to support Maya epigraphic analysis

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Abstract: This paper presents an overview of a research project integrating epigraphy and computer science, which has developed a number of visual analysis methods for segmentation, classification, indexing, and retrieval of Maya glyphs in ancient codices. The paper summarizes the technical aspects of the methods developed for these tasks, including preparation of source materials, creation of a data repository, segmentation of glyph strokes, classification of single glyphs, and visualization of glyph collections. The developed methods, based on computer vision and machine learning, are generic and could be applicable to other sources of visual data in the digital humanities.

Keywords: MAAYA project, Maya glyphs, computer vision, machine learning.

Resumen: Este artículo presenta una introducción a un proyecto de investigación que, al integrar epigrafía y ciencias de la computación, ha desarrollado métodos de análisis visual para segmentar, clasificar, indexar y recuperar glifos mayas en códices antiguos. El artículo resume los aspectos técnicos principales de los métodos desarrollados para estas tareas, incluyendo la preparación de materiales, la creación de una base de datos, la segmentación de trazos de glifos, la clasificación de glifos individuales, y la visualización de colecciones de glifos. Los métodos desarrollados, basados en visión y aprendizaje artificial, son generales y podrían aplicarse a otras fuentes de datos visuales en las humanidades digitales.

Palabras clave: proyecto MAAYA, glifos mayas, visión artificial, aprendizaje automatizado.

INTRODUCTION

The Maya civilization flourished in Mesoamerica since the Late Preclassic period extending into the Postclassic. Experts on Maya epigraphy have deciphered many of the hieroglyphic writings of the ancient Maya over the past 200 years (Macri & Vail, 2009). Epigraphic recordings are found in codices, monuments, and ceramics across archaeological sites, as well as in museums and institutions in Mexico, Central America, Europe and the USA. As the field of Digital Humanities starts to make its way into the epigraphy domain, it is clear that computational methods and tools will be increasingly needed to facilitate and accelerate the daily work of scholars, supporting the investigation of new, possibly data-driven research-hypotheses, and for helping to train students in this discipline.

In this paper, we present an overview of MAAYA, a project that integrates the work of epigraphists and computer scientists with three goals. The first one is the development of computational methods

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for visual analysis to segment, classify, index, and retrieve Maya glyphs from the three original surviving Maya codices, hosted in European institutions in the cities of Dresden, Madrid, and Paris. The second goal was the development of online information management tools designed to support annotation, search, retrieval, and visualization tasks. Finally, the third, long-term goal is the advancement of Maya epigraphy through the use of these tools.

The paper summarizes work on some of the main modules needed to achieve these goals. This includes the preparation of codex source materials and the creation of a data repository (Section 2); methods for automatic visual analysis, including segmentation of glyph strokes (Section 3) and glyph classification (Section 4); and methods for visualization and browsing of glyph data (Section 5). Most of the content of this paper was originally presented in (Hu *et al*., 2015; Can, Odobez, & Gatica-Perez, 2016; Hu, Odobez, & Gatica-Perez, 2017; and Roman-Rangel *et al*., 2016). We conclude the paper with some thoughts on future work in Section 6.

DATA SOURCES AND MULTIMEDIA REPOSITORY

Although the codices' exact origin and dating are not entirely known, they were produced in all likelihood within the greater Peninsula of Yucatan during the Postclassic period. The primary data sources are existing reproductions, photographs, and digital scans of the three ancient Maya codices preserved in Germany (Saxon State and University Library Dresden, Dresden), Spain (Museo de America, Madrid), and France (Biblioteque Nationale de France, Paris). Other datasets used in the project involve monument-related data, but are not discussed here for space reasons.

The production of a Digital Multimedia Repository (DMR) of Maya hieroglyphic texts and iconography involved researchers at the University of Bonn (C. Pallan Gayol, G. Krempel, and P. Biro), research partners at New College of Florida (G. Vail, M. Mermell, H. Neville and E. Cassell) and the Comenius University of Bratislava (J. Špótak). This repository focuses on the production of high-quality clean raster and vectorial visualizations for all hieroglyphic and iconographic data within the Maya codices, with each element linked to a corresponding database record. The Digital Multimedia Repository approaches the codices at different scales or levels of detail:

1. Entire codex overview
2. Thematic sections into which each codex is subdivided
3. Almanacs
4. *T'ols*[8]
5. Frames
6. Individual elements (main text glyph-blocks; calendric glyph-blocks, captions, icons)
7. Individual signs or individual iconic elements

The production of both the Digital Multimedia Repository and the derived datasets involves a number of steps. Roughly, the process includes: *a)* advanced image enhancement and post-processing of existing documentation of the codex data sources, including upsizing to 400 per cent normal size, edge refinement, high dynamic range (HDR) tone mapping, noise reduction, and unsharp masking; *b)* production of templates providing a mapping of all textual and iconographic elements within any given t'ol of the codices; *c)* cropping of enhanced and upsized images segmented at the glyph-block-level; *d)* generation of clean-raster images separating the cultural information (brushstrokes) from background noise and preservation accidents; and *e)* production of high-quality vectorial images, including colour/grayscale forms, simplified binary forms showing only black and white information, and generation of blue vectorial forms providing informed reconstructions based on available comparative evidence of all instances of the same sign within the codices (see Figure 1).

Annotation of the glyph collocations was performed on an online server-like capture tool (relying on Filemaker Pro 12), enabling real-time annotation capabilities. Importantly, to facilitate semi-automatic annotation of the glyph-collocations and glyph-

[8] A *t'ol* is a Yucatec Maya term used to refer to each subdivision of a Maya Codex's almanac (Thompson, 1972, p. 2). Also known as frames or clauses, usually multiple *t'ols* appear "nested" within a page register, each comprising a group of glyphs and a picture associated with a specific augury and their correspondent calendric dates.

Figure 1. Process to generate vectorial representations of the Dresden Codex: from colour images to binary images to reconstructed (blue) shapes. *a)* Noisy raster; *b)* Clean raster; *c)* Grayscale vectors; *d)* Binary vectors; *e)* Blue-reconstructed vectors; *f)* Composite showing blue and grayscale vectors. Image by Carlos Pallán Gayol based on a SLUB Library (Dresden) open-access image available at: http://www.slub-dresden.de/sammlungen/digitale-sammlungen/werkansicht/cache.off?tx_dlf[id]=2967

strings within the codices, we developed a glyph-concordance tool able to cross-reference four different glyph catalogues (Thompson, 1962; Evrenov, Kosarev, & Ustinov, 1961; Macri & Vail, 2009; Zimmermann, 1956), which radically reduces the amount of time required when compared to traditional (manually-based) annotation. It also allows advanced multiple co-occurrence queries by cross-referencing the above mentioned catalogues.

From the various datasets produced or used in the project, the Maya Codex Dataset comprises a selection of annotated raster and vectorial renderings of hieroglyphs which, as the name implies, stems exclusively from the codices, and which includes both syllabic signs (that correspond to syllables) as well as logographic signs (that correspond to concepts). This dataset was developed primarily by a team of epigraphists working at the University of Bonn (Pallan, Krempel), the New College of Florida (Vail) and the University of Bratislava (Špoták). Its production steps are therefore analogous to those outlined above for the Digital Multimedia Repository repository.

SEGMENTATION OF GLYPH STROKES

The surviving ancient Maya codices often lose their visual quality over time. In addition to the fading of ink, background noise is often introduced due to deterioration of the material, ink stains, etc.

Extracting clean glyph strokes from raw images of the ancient scripts is a challenging, yet crucial step for any further automatic document image analysis tasks such as page layout analysis, character recognition, and others. In this section, we present a system for automatically extracting hieroglyph strokes from images of degraded ancient Maya codices, presented at length in (Hu, Odobez, & Gatica-Perez, 2017). Our system adopts a region-based image segmentation framework.

Raw glyph block images are first represented by over-segmented homogeneous image regions using the Simple Linear Iterative Clustering (SLIC) algorithm, which clusters image pixels into local, compact, homogeneous, and edge-aware regions, also called super-pixels (Achanta *et al*., 2012). Figure 2 illustrates the super-pixel representation of examples of glyph

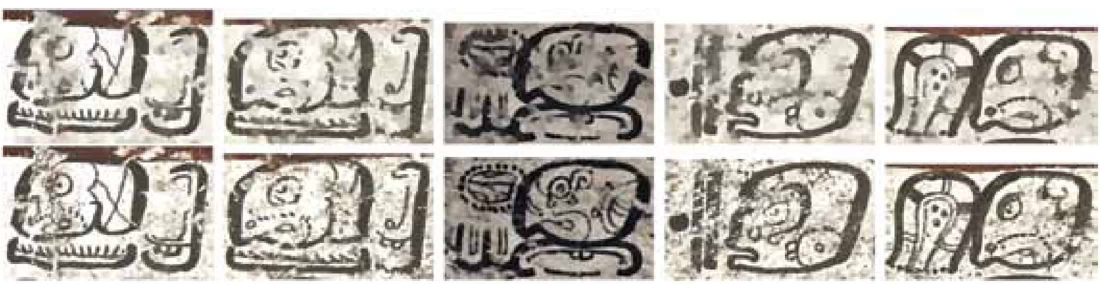

Figure 2. Super-pixel representation of glyph block images using different pre-defined numbers of regions: (top row) 500 regions; (bottom row) 2000 regions. Each super-pixel is displayed using the average colour of pixels within that region. Figure adapted from (Hu *et al.,* 2017).

block images at two different resolution scales (*i.e.* different number of regions).

The number of super-pixels extracted is a key factor that will affect the glyph binarization result. A larger number leads to binarization results that better preserve details such as thin glyph strokes. However, this also keeps more background noise. In contrast, a smaller number of super-pixels leads to a coarser image presentation resolution, and yields a cleaner binarization result. However, it will tend to lose more delicate glyph stroke details. As a result of these observations, we built our system using multiple resolution super-pixel regions. A support vector machine (SVM) classifier was used to label each super-pixel region with a number that expresses its probability to belong to foreground glyph strokes. Pixel-wise probability maps from multiple super-pixel resolution scales are then aggregated to cope with various stroke widths and background noise. Images in the top row of Figure 3 show the segmentation results using this method.

Finally, a fully connected Conditional Random Field (CRF) model (Krahenbühl & Koltun, 2011) is applied to improve the labelling consistency. Comparing the segmentation results in the bottom row to those of the top row in Figure 3, we can see that more delicate details are preserved by using the fully connected CRF model.

From the results we can see that our method preserves stroke details and reduces background noise. As an application in (Hu, Odobez, & Gatica Perez, 2017), we conducted glyph retrieval experiments using manually produced clean raster images (generated by the epigraphers in our team) and our automatically generated glyph strokes. Experimental results show that the machine-extracted glyph strokes achieve comparable retrieval results to those obtained using glyphs manually segmented by epigraphers. This is a positive result, as it enables the processing of raw data in later tasks.

VISUAL CLASSIFICATION OF SINGLE GLYPHS

Robust shape representations are critical for visual analysis of glyphs. We have studied and compared two types of shape representations in a bag-of-words based pipeline to recognize Maya glyphs in (Can, Odobez, & Gatica Perez, 2016). The first representation is a knowledge-driven descriptor, called Histogram of Orientation Shape Context (HOOSC) (Roman-Rangel *et al.*, 2011). The second one is a data-driven representation obtained by applying an unsupervised Sparse Autoencoder (SA), a classic model in machine learning (Hinton & Zemel, 1994).

Both methods operate on a finite set of points sampled from the binary shape that represents a glyph.

Figure 3. Segmentation results using only the appearance component (top row); and with the fully connected CRF model based regulation method. Figure adapted from (Hu *et al.,* 2017).

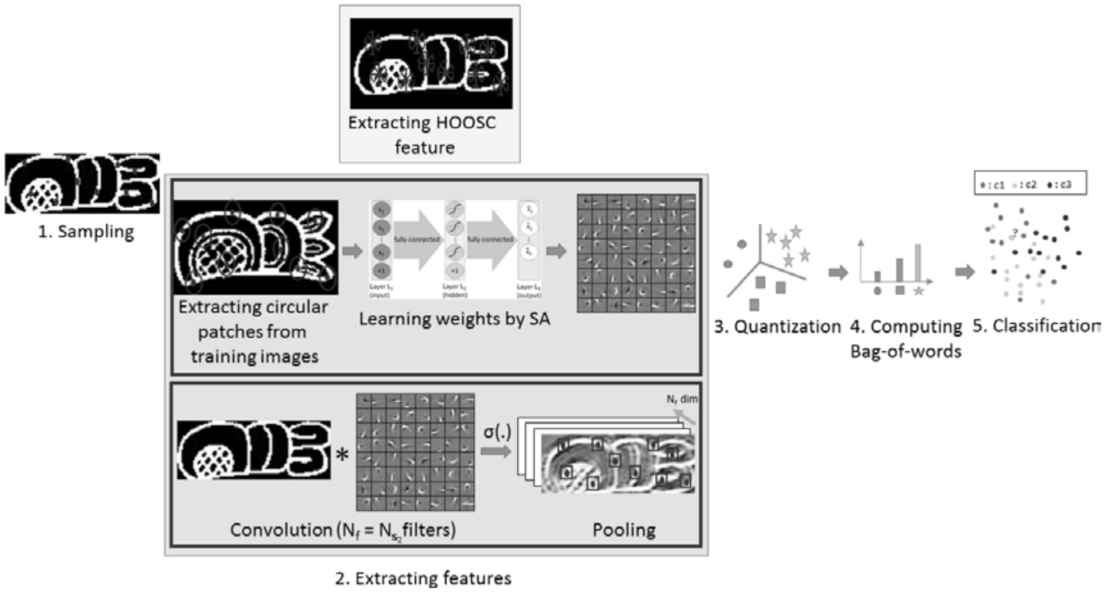

Figure 4. Glyph classification system. For feature computation, either the HOOSC method (top block) or the SA method (bottom block) can be used. The SA approach requires a learning phase. Figure taken from Can *et al.,* 2016.

Figure 4 illustrates the bag-of-words pipeline used for our comparative study. For the same set of points sampled from each shape, we compute both the HOOSC and SA representations. The HOOSC descriptor is defined on a circular grid centred on each point and computes the histogram of orientations of the contours over the grid. The SA representation requires a learning phase from raw pixel values. The learned filters for the SA representation reveal the type of image content (see gray-level basic shapes that appear in the bottom block), and are tuned to the inherent motifs in the shape data.

These representations have been evaluated both on Maya glyph data (a 10-class set of single glyphs, which is a small subset of all glyph categories that are present in the codices), and a larger-scale hand-drawn sketch dataset, spanning 250 classes of general objects (Eitz, Hays, & Alexa, 2012), to test the generalization ability of the descriptors. We evaluated the performance of both representations with different parameter settings.

From the experiments, the HOOSC descriptor performed better than the SA representation on the smaller dataset (glyph), for which the HOOSC descriptor was originally designed for. In contrast, when other data sets are considered (10-class experiments on sketches) and more classes are present (250 sketch classes), the SA representation was able to surpass the HOOSC descriptor (29.3% vs. 20.7% on the 250-class experiments). This shows the importance (and the necessity) of significant data volumes for data-driven approaches. We also observed that using a larger number of parameters in the SA method (specifically, the number of "hidden units" in the model) improved the performance.

With dense sampling, that is, when more points are used as the basis to compute the descriptors, the HOOSC descriptor improved substantially, especially if large enough spatial regions are considered, reaching 35 per cent accuracy on the 250-class case, in pair with that of (Eitz, Hay, & Alexa, 2012). On the other hand, the SA representation did not benefit from this factor, due to the quadratic increase of parameters during the learning phase.

Overall, this study, using both Maya hieroglyphics and generic hand-drawn shapes, informs about the performance trends of the studied methods, and could also be informative for their possible use on other cultural heritage sources of visual shapes. This includes other Maya glyph datasets and other sources, for instance Egyptian hieroglyphs.

BROWSING COLLECTIONS OF GLYPH BLOCKS

A major objective of research in archaeology consists in interpreting traces left by past activities. Once discovered, every such trace is documented for its intrinsic properties, such as geographic location or estimated date of origin. This allows archaeologists to discover high-level patterns that can then be interpreted for their high-level meaning, *e.g.*, semantics. Whereas the diversity and volume of collected traces may make this task very complex and tedious, machine intelligence could support this action by its capabilities to reason over large and diverse sets of items at once. We therefore advocate the use of machine learning capabilities in the context of data exploration and, in particular, the creation of systematic similarity-based organization of this data.

In the case of Maya hieroglyph decipherment, epigraphers document their findings based on the place the writing was found or the type of artefact it appeared on. From this factual information, they hypothesize further interpretations of the content, based on any contextual information they may exploit. Here, information technologies may be help by providing large browsable catalogues in which to situate the piece in question in terms of estimated date of origin, similar locations, or more perceptual information such as visual similarity. In the further particular case of Maya codices, this strategy has allowed to break down the codices into pieces at various interpretation levels, such as pages, t'ols (*i.e.* registers), glyph blocks, iconic blocks, or calendrics.

We have thus built several browse and search structures over these collections by defining similarity measurements on inferred intrinsic or perceptual properties (Sun *et al*., 2015; Marchand-Maillet *et al*., 2016). We could thus provide epigraphers with interfaces allowing tasks such as browsing codices per item (*i.e.*, page, t'ol, glyph-block, etc.), browsing per string of glyph codes a.k.a., T-string, browsing glyphs and glyph-blocks per visual similarity, browsing per annotation similarity, searching T-Strings, counting co-occurrences, etc. This is illustrated in Figure 5.

These interfaces are built upon mathematical descriptors, which for the case of browsing by visual similarity correspond to a collection of numeric values that captures statistics about the visual information

Figure 5. Example of a browser of glyph blocks that uses visual similarity to place similar blocks in adjacent positions.

of a hieroglyph of interest, like the HOOSC descriptor described in the previous section (Roman-Rangel *et al*., 2011; Hu *et al*., 2015). Having such descriptors makes easier to perform efficient comparison of visual elements from a mathematical point of view. In this regard, we have described Maya hieroglyphs at the level of detail of glyph-blocks in our project. For this, the descriptors must be robust enough to account for visual variations of the individual glyph-signs like changes in rotation or scaling, and they must also capture visual similarity across different signs (Roman-Rangel *et al*., 2011). Furthermore, ideally they must be as short as possible *(i.e.*, of low-dimensionality), such that it is computationally efficient to perform browsing and retrieval operations on them.

In our work, we have investigated the impact of using histograms of local descriptors like HOOSC, as well as neural representations for such representations (Roman-Rangel *et al.*, 2016). Local descriptors are statistics describing shape characteristics at different locations of an image. Since they correspond to handcrafted methods tailored for specific purposes, (*e.g.*, description of hieroglyphs in our case), they have high potential for effective browsing.

In contrast, neural representations are methods that rely on learning strategies that can learn a wide variety of complex mathematical functions. Therefore, they are able to estimate more robust representations of glyph-blocks in comparison to local descriptors, and in practice they can perform well in different learning tasks. Namely, our work shows that they obtain high retrieval performance when dealing with glyph-blocks. One limitation of neural representations is that they require large amounts of data to ensure accuracy in their training. Since the amount of available Maya glyphs is limited to the existing codices, we risk to end up with models representing only a subset of the potentially larger existing variations of hieroglyphs; that is, glyph-blocks that might be under-represented by the resulting neural models, with the potential consequence of not recognizing new instances of, otherwise assumed, known signs. To address this issue, we have investigated the impact of combining local descriptors with neural representations (Roman-Rangel & Marchand-Maillet, 2016). In this case, we use neural models to compute representations of specific locations within an image, for a latter combination of such representations that provide a full glyph-block description. Our results show that this approach is promising, as it obtains state-of-the-art performance.

As previously mentioned, one characteristic of the image representation is that they are of low dimensionality. This not only accounts for efficient computational processing, but it could also allow showing glyph-blocks in 2-D browsing interfaces. For this, we are currently investigating dimensionality reduction techniques to produce mathematical representations of glyph-blocks of two dimensions, such that signs that are visually similar to one another are placed closer to those that are visually different. We hope to integrate such approach in future versions of our current browsing interfaces.

CONCLUSION

We presented an overview of the MAAYA project, summarizing work on data preparation and annotation, glyph stroke segmentation, glyph classification, and glyph visualization and browsing. Based on what the project achieved, there are several opportunities for future research in this domain. We briefly comment on two of them.

First, the generation of a digital dataset of the glyphs present in the three codices under study is a milestone of our work, because it has enabled the development and objective evaluation of a variety of methods of visual analysis and visualization. The data and methods could thus be relevant for other researchers working in ancient Maya epigraphy. More generally, the computer vision and machine learning methods summarized here could be applicable to other sources of data in the digital humanities, as they are generic and thus potentially amenable to other problems.

Second, there is a need to deepen the understanding on how scholars and other potential users (*e.g.* novice students in the discipline and the general public) could best benefit from the methods we have developed. This can be framed as a human-computer interaction (HCI) problem. The collaboration across computing and epigraphy produced a couple of designs of interfaces, as well as initial results on how the presented information is perceived and analysed by experts. However, the space for improving these initial prototypes and to adapt them to different potential users is significant. We believe this is an area that future work needs to address.

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Al igual que otras disciplinas científicas, la arqueología se ha beneficiado desde hace décadas de las innovaciones producidas por la revolución informática. En la actualidad, la eficacia de métodos computacionales y técnicas digitales para estudiar el pasado ha alcanzado un nivel tan alto que tareas fundamentales, como el registro de datos, la clasificación de artefactos, la evaluación de modelos de evolución histórica, la exhibición y difusión del patrimonio cultural, entre muchas otras, no pueden concebirse sin un enfoque cuantitativo facilitado por un ordenador electrónico.

En este libro se presentan 18 trabajos que demuestran el potencial de los métodos computacionales en la documentación, análisis y difusión del patrimonio cultural. El volumen es resultado del trabajo de 32 miembros de la Red de Tecnologías Digitales para la Difusión del Patrimonio Cultural (RedTDPC), una organización académica que reúne a más de 250 investigadores, estudiantes, gestores culturales y agentes de los sectores público y privado interesados en investigar las condiciones técnicas, intelectuales, legales y económicas para que las tecnologías digitales puedan ayudar a las instituciones culturales a mejorar el análisis, la difusión y la divulgación del patrimonio cultural. La RedTDPC opera desde el Instituto Nacional de Antropología e Historia gracias al financiamiento del Programa de Redes Temáticas del Consejo Nacional de Ciencia y Tecnología. Con la publicación de este libro, la RedTDPC trata de llenar un vacío en la bibliografía mexicana sobre arqueología computacional y espera fomentar, entre estudiantes e investigadores, un interés mayor en este importante tema.

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