From Papyrus to Pixels: Optical Character Recognition Applied to Ancient Egyptian Hieratic

by

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Dedicated to anyone who has ever digitized a document, offered scholarly tools without cost, or contributed in any other way to making academic research more accessible and free for all

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Overview

This thesis outlines an attempt to use Optical Character Recognition (OCR) to investigate the morphology of Middle Egyptian Hieratic, a cursive ancient Egyptian script. First, the introduction will discuss the justification and purpose of the work ("Introduction"). Then, there will be a review of OCR literature, focusing on its previous applications in the field of Egyptology ("Optical Character Recognition Review"). Next, Egyptological background will be discussed, including detailed information about each text looked at in this study ("Background"), followed by information on the facsimiles of the texts ("Sources for the Data Set"). Then, there will be a lengthy description of the techniques and procedures used to produce the data set and the various programs used for analysis ("Methods"). Finally, the results of the analysis and their implications will be addressed ("Results and Discussion") and a brief conclusion will be provided ("Conclusion and Future Directions"). The results indicate the successful implementation of OCR methods and their potential for analysis on wide ranging questions, such as the similarities between the writings of different signs to the provenance of texts of unknown origin.

Introduction

Paleography, the study of ancient writing systems, is a vital area of research when analyzing ancient texts.[1] At the basic level, those who study paleography are concerned with identifying and interpreting ancient signs, allowing ancient texts to be understood. The full meaning of a text, and thus its historical or literary value, often cannot be gleaned until a paleographic approach is used at a deeper level as well. For example, identifying unusual written symbols, determining the age or provenance of a text based on the morphology of the characters, and sometimes even determining the author of a text are all within the realm of paleography. Studies reaching for this aim of recognizing ancient signs and all that stems from it have historically had to be limited in some way, not by oversight, but by necessity. The large sign identification works, such as Möller's paleography for ancient Egyptian hieratic, only include a few of each sign to try and catalog the variation present in the corpus.[2] This is demanded by the fact that no human could possibly record all existing signs, let alone adequately use that data if it was available. On the other hand, comparative works that attempt to analyze much more variation per sign have to limit their scope to specific eras or questions for the very same reason.[3] Other investigations into paleography happen in the commentaries and footnotes of discussions about individual works, using the information collected by the more comprehensive paleographical studies.

For decades, this system has been the best solution to the problem of how to deal with paleography, deliberately limiting data sets and questions, while feeding into and from integrated works. The sign identification works assist scholars in determining signs in a new text, the comparative works allow the use of similar texts to help with particularly problematic signs, and specialized information is helpful for answering some of the deeper level questions, such as the age, provenance, or author of a text. While this system works well for humans, some questions are still out of reach. For example, one interested in the paleography of a language or writing system as a whole would be unable to adequately investigate this, given the sheer amount of data that would need to be examined. Even for the comparative works mentioned above, all human-driven studies must be limited in the number of signs examined. Another question unable to be answered by older paleographical methods is the exact similarity between signs. One can make a claim that one sign is morphologically different from another, but, due to the subjective nature of such hypotheses, there are few ways to test overall similarity empirically. Paleography, by nature, has always attempted to be at least somewhat objective, creating facsimiles to be as

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[1] The drawing on the title page was created by the author, with reference and colors from an image of the 18th Dynasty Tomb of Menna from: Wilson, Hilary. "Scribe like an Egyptian." *History Today*, August 8, 2019. https://www.historytoday.com/miscellanies/scribe-egyptian.

[2] Möller, Georg. *Hieratische Paläographie: Die Aegyptische Buchschrift in ihrer Entwicklung von der Fünften Dynastie bis zur Römischen Kaiserzeit: I. Band: Bis zum Beginn der Achtzehnten Dynastie.* J.C. Hinrichs, Leipzig (1909).

[3] El-Aguizy, Ola. "A Palaeographical Study of Demotic Papyri in the Cairo Museum from the Reign of King Taharka to the End of the Ptolemaic Period." *Enchoria: Zeitschrift für Demostistik und Koptologie* 14 (1986): 67–70.

close to original texts as possible, using statistics to analyze shapes and distributions of characters, and aiming to accurately recover damaged sections of text.[4] In this way, statistical methods can be used for similarity studies, but, with even a small amount of texts producing a data set, the number of avenues for study increases exponentially and it is not possible for anyone to accurately address all of the data. It is no wonder that such research using statistical paleographic methods usually significantly limited their scope.[5]

Now, in the digital age, there is a solution. Modern computers have the computational power to analyze amounts of data far beyond what an individual or even groups of individuals can do. Hundreds of thousands of data points can be analyzed in seconds, allowing elements of paleography to be compared over wide swathes of the available corpus. What was once only feasible as the result of a scholar's life's work can now be done in an instant at the push of a button. In addition, computers can carry far fewer biases than humans, provided they are set up correctly. However, if care is not taken, computer algorithms can replicate and even multiply human biases.[6] This demonstrates the importance of having the creators and users of such computer analyses be people trained in the field of the material being analyzed. Only someone who is familiar with the texts being examined can adequately troubleshoot such a program.

Provided that the programs are created correctly, digital analysis of ancient material has the potential to reveal information previously inaccessible due to limited and time-consuming methods, as well as data sets too large for humans. An ideal paleographical program would be able to review digitized material (or even digitize the material itself), extract the relevant information, and compare that information to all previously collected data in a useful and reproducible way. Beyond this, the digitization of analyses and actual texts can only benefit a field, allowing information to be more accessible and usable by anyone, furthering the collective knowledge.

When it comes to integral programs for the digital study of paleography, there are few more important than Optical Character Recognition (OCR) programs. In brief, OCR programs convert physical writing into a machine-readable format. This can take many forms and has wide ranging applications in a myriad of disciplines. The types of algorithms used for OCR range from simple pixel comparisons to complex machine learning models, but the question they intend to answer is the same: when given a written character, what is its identity?[7] When applied to ancient material, OCR programs can be used to automatically identify characters and, when trained enough, even make inferences about partial characters, notably taking some of the guesswork out of identifying ones that are unusual or partially preserved. A researcher will still have to make a judgment call of whether to accept or reject the program's suggestion for any

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[4] Stokes, Peter A. "Digital approaches to paleography and book history: some challenges, present and future." *Front. Digit. Humanit.* 2:5. (2015).

[5] Gilissen, Léon. *L'expertise des écritures médiévales : recherche d'une méthode avec application à un manuscrit du XIe siècle : le Lectionnaire de Lobbes : codex bruxellensis 18018.* E. Story-Scientia, 1973.

[6] Caliskan, Aylin, Joanna J. Bryson, and Arvind Narayanan. "Semantics Derived Automatically from Language Corpora Contain Human-like Biases." *Science* 356, no. 6334 (2017): 183–86.

[7] Memon, Jamshed, Maira Sami, Rizwan Ahmed Khan, and Mueen Uddin. "Handwritten optical character recognition (OCR): A comprehensive systematic literature review (SLR)." *IEEE Access 8* (2020): 142642-142668.

given character, but OCR methods will at least provide a reproducible baseline. Also, OCR programs can allow for the rapid digitization of texts, as all one needs to do is input a text and let the machine encode the identities of all of the characters.

Optical Character Recognition has been used in Egyptology for over a decade, often to great effect.[8,9] However, the goals of most of the previous OCR programs in the field have started and ended with the aforementioned digital identification of characters and digital transcribing of texts. This is important work, but OCR is not limited to this use. For nearly all OCR algorithms to identify a character, the program must look at a database of previously correctly identified characters to inform the new decision. When determining what an unknown character is, the program uses the database to rank its options and decide upon the best one. This process of comparing the similarities of the input character to the characters in the database allows for image recognition, but it can also provide a wealth of information about character similarity. This information can then be used to test hypotheses about texts. For instance, if one hypothesized that two texts were written by the same scribe, one could compare the handwritings of the texts. Indeed, this is already one thing that is done to investigate these questions, but the power, reliability, and statistical significance of these studies would be greatly improved if there was a large data set for comparisons. Then, one could not only claim that the handwriting of two texts seem to be similar, but that they are also markedly different from the whole corpus of other texts. This way of comparing texts is only possible using OCR and a large data set.

OCR has been used on data sets of hieroglyphs[10,11] and handwritten hieroglyphic transcriptions,[12] but never hieratic, the predominant ancient Egyptian cursive script. Hieratic poses unique challenges to OCR due to the variability of papyrus quality, the presence of ligatures and overlapping characters, which OCR programs cannot separate, variations in ink density, and other such features. Despite the difficulty of applying an OCR based approach to the study of hieratic, it is necessary work. Many questions, such as the authorship and provenance of texts or the identification of scribal schools, only make sense when considering hieratic morphology. In addition, the automatic identification of hieratic characters has great potential to be useful for students and experienced scholars alike, in a way that hieroglyphic identification is not. Infrequently does one mistake what a hieroglyphic sign is, but this is common in hieratic where signs can meld together, be smudged, or just look similar by design. The use of digital methods, such as OCR, on hieratic will allow larger questions to be investigated, easier study of

[8] Nederhof, Mark-Jan, and M. Berti. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).
[9] Franken, Morris, and Jan C. van Gemert. "Automatic Egyptian hieroglyph recognition by retrieving images as texts." In *Proceedings of the 21st ACM international conference on Multimedia*, pp. 765-768. 2013.
[10] Franken, Morris, and Jan C. van Gemert. "Automatic Egyptian hieroglyph recognition by retrieving images as texts." In *Proceedings of the 21st ACM international conference on Multimedia*, pp. 765-768. 2013.
[11] Elnabawy, Reham, Rimon Elias and Mohammed A.-M. Salem. "Image Based Hieroglyphic Character Recognition." In *2018 14th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS)* (2018): 32-39.
[12] Nederhof, Mark-Jan, and M. Berti. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).

the ancient material, more accessible and locatable resources, and will aid new scholars learning the script. Given all of this, there were three main goals for this project:

1. to create a large, digital hieratic data set for use in OCR algorithms and the tools to allow others to easily add to the data set
2. to create an OCR program that can analyze the data set and reliably identify hieratic characters
3. to demonstrate some of the potential applications of these tools and the types of information that can be gained by their usage, investigating relevant textual questions, such as provenance information

A secondary, but no less important, goal of this work, was to make the tools (the data set and the hieratic OCR tool) created by this project completely open-source and free for anyone to use. This will be instrumental in future work, as the program itself can be used to expand the data set, so no future scholar has to go through all of their material manually. With every new person who uses the program, the program should only become better and, by making the code open-source, other researchers should be able to modify it, further improving its capabilities.

To produce the data set, I meticulously created a Shipwrecked Sailor facsimile and part of an Eloquent Peasant facsimile, two texts chosen for their length and the wealth of published information about them, as well as the easily obtainable, clear photographs of them.[13,14] I then annotated each individual character in those facsimiles, along with many facsimiles from Möller[15] and one from Poe,[16] in Adobe Photoshop. The facsimiles I used capture a reasonable amount of variation in provenance, text genre, and modern facsimile creator, making the data set robust and apt for various comparisons. All original texts are also approximately dated to the Middle Kingdom in order to try and control for the date of creation affecting the variations between texts. In that same vein, the usage of facsimiles, rather than the original texts, was a conscious decision to limit some of the places mentioned above where hieratic varies in ways other than handwriting: ink density/darkness, photo quality, papyrus quality, lighting, and more. To use the original texts is not within the scope of this project and would likely require a much larger data set than I was able to create. I worked with Dr. Christian Casey to develop Sobti, a program that cuts out the annotated hieratic characters from each facsimile. Then, the individual characters were each annotated with their Gardiner sign code,[17] location, original text, and

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[13] Golénischeff, W. *Les Papyrus Hieratiques No 1115, 1116A et 1116B de l'Ermitage Imperial a St Petersbourg*. St Petersburg: Ermitage Imperial, 1913.
[14] Parkinson, Richard B. and Baylis, Lisa. *Four 12th Dynasty Literary Papyri (Pap. Berlin P. 3022-5): A Photographic Record*. Berlin: Akademie Verlag, 2012.
[15] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1
[16] Poe, William Clay. *The Writing of a Skillful Scribe: An Introduction to Hieratic Middle Egyptian Through the Text of the Shipwrecked Sailor*. Sonoma State University, 2008.
[17] Gardiner, Alan H. *Egyptian Grammar: Being an Introduction to the Study of Hieroglyphs.* 3. ed., Oxford: Griffith Institution, 1957.

facsimile maker. This has resulted in a data set of 13,134 individual signs, by far the largest data set of its kind in the field.

I then created an OCR program to analyze the data set. This program uses an Image Distortion Model to compare characters, which was heavily inspired by the work of Nederhof (2015) and partly produced in collaboration with Dr. Nederhof.[18] The program is able to output how similar an image is to each image in the data set, providing a metric for the identification of signs and the large-scale comparison of texts by morphology. I have used the program to identify known signs, testing its accuracy, as well as to investigate important questions, demonstrating its greater utility. To do these investigations, Uniform Manifold Approximation and Projection (UMAP) plots were created, reducing the dimensionality of the data and making it easily interpretable through clustering on a graph.

The program is suitable for the investigation of numerous questions, but a few interesting ones were chosen as a focus. First, the program was tested to make sure it could adequately distinguish between signs of very different morphologies (A2 and Aa1). Then, a couple pairs of signs that often look indistinguishable to the human eye were tested to see if there are underlying morphological differences that the machine is picking up on that humans have not.

In this same vein, the role of sign "tails" was also investigated. Certain signs, especially those that end in a stroke that curves downward, sometimes have their final strokes extended down, if there is space for it. These strokes, often referred to as tails, are a distinctive feature of hieratic, but have also been hypothesized to be arbitrary, lacking the distinctive handwriting information present in the shape of the rest of the sign.[19] To probe this common assumption, all of the tails of the large variant of the A1 sign were cut. Then, the program's results for the data set with tails and the data set without tails were compared, to see if the signs better convey information with or without the tails (i.e. for which data set the signs cluster more by text on the UMAP graph).

The role of modern facsimile makers was also tested. This was in order to make sure that modern facsimile makers do not add too much of their own handwriting into their facsimiles, obscuring the original variation present in the texts. This was both to test modern facsimile methods, as well as the program's ability to look past modern handwriting and see the original hieratic handwriting, even when the modern facsimiles are very simplified, such as in the case of Poe's.

After this, the program was used to explore the current hypothesis that the Shipwrecked Sailor and Papyrus Prisse were written in the same hand.[20] To do this, the similarity between the signs from the two texts was tested. The program was used to test signs with easily discernible differences, as well as check for deeper differences beyond what the human eye can see in other

[18] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).
[19] Dr. Brian Muhs (Associate Professor of Egyptology, University of Chicago) in discussion with the author, November 2021.
[20] von Bomhard, Anne-Sophie. "Le conte du naufragé et le papyrus Prisse." *Revue d'Égyptologie* 50 (1999): 51-65.

signs. Here, the program demonstrated its utility to validate or counter existing work from its unique angle of analysis.

Another comparison was done for the three texts from Lahun in the data set, to see if the program could distinguish sign form commonalities in separate texts from the same provenance. This test bodes well for the eventual usage of the program to compare the writing styles from different provenances or even scribal schools. It is also a good sign for the future ability of the program to identify the provenance of texts of unknown origin that are not in the same handwriting as another text. Out of this comparison, an observation was made about the similar writing of unusual G1 signs in the Lahun texts and the Story of Sinuhe, a text of Theban origin. The similarities between the Sinuhe texts and the Lahun material were also looked at. The program was also unsuccessfully used to compare genres of texts, but, from that study, a fascinating comparison of Papyrus Ebers and the Rhind Papyrus was made. Finally, Papyrus Westcar was looked at on its own and, even though its exact provenance could not be determined, the program was able to offer a fascinating look at its morphology, particularly for some of its most unique writings of signs.

These various studies were done for two reasons. First, to learn more about hieratic and the specific texts that compose the data set presented in this paper. Just as important, however, is the demonstration that the OCR program developed in this work is operational, powerful, and useful as a learning and research tool. In summary, this project provides a proof-of-concept for the future use of Optical Character Recognition for hieratic and offers a program that can be built upon in the future. The open-source program will be available to all, along with a free, large data set, allowing anyone to make reliable and easy hieratic character identifications, as well as massive corpus-wide hieratic comparisons. The results from the program will hopefully be able to inform future decisions about facsimile creation and subsequent directions for traditional hieratic paleographical research. The open-source nature of the program will hopefully lead to rapid improvements of the program and the data set, exponentially increasing the abilities and benefits of this technology.

Optical Character Recognition Review

In essence, the goal of Optical Character Recognition (OCR) is the conversion of physical text, whether it be printed, handwritten, or carved, to a machine readable, digital format that can be easily read, searched, analyzed, and edited. Although there are a multitude of ways to reach this goal, the general steps remain the same. First, a program is constructed to identify characters. Then, it is trained on a data set of characters already identified. The program is then optimized, either by humans or, in the cases of neural networks, by the program itself, to be as accurate as possible in its analysis of the data. Finally, the completed program can be used to identify new characters quickly and accurately. This allows for rapid digitization of written documents, better identification of unusual or otherwise hard to read texts, and even extrapolation based on probabilities for damaged texts.

Creating a machine able to automatically recognize physical writing is not a new concept. In fact, ideas for what we now call Optical Character Recognition have been around since at least the 1920s.[21] Despite this, it was not until the rise of computers that OCR was actually able to be put into practice. Early computers in the 1940s, 50s, and 60s were applied to OCR problems to varying degrees of success.[22] In the following decades, great advancements were made as computers became faster and algorithms became more refined. This process was by no means linear, as branches of the field grew and took different forms, adapting and inventing new programs for a wide variety of OCR questions. Currently, OCR is ubiquitous around the world and is supported by plenty of in-depth and advanced research.

OCR has uses in nearly every facet of life and in nearly every field. For example, OCR programs have been used to automatically read checks,[23] passports,[24] mail,[25] and more, drastically improving data processing speeds. OCR programs have been demonstrated on numerous extant and ancient languages around the world including, but certainly not limited to

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[21] Mori, Shunji, Ching Y. Suen, and Kazuhiko Yamamoto. “Historical Review of OCR Research and Development.” *Proceedings of the IEEE* 80, no. 7 (1992): 1029–58. https://doi.org/10.1109/5.156468.

[22] Memon, Jamshed, Maira Sami, Rizwan Ahmed Khan, and Mueen Uddin. "Handwritten optical character recognition (OCR): A comprehensive systematic literature review (SLR)." *IEEE Access* 8 (2020): 142642-142668.

[23] Srivastava, Shriansh, J. Priyadarshini, Sachin Gopal, Sanchay Gupta, and Har Shobhit Dayal. "Optical character recognition on bank cheques using 2D convolution neural network." In *Applications of Artificial Intelligence Techniques in Engineering*, pp. 589-596. Springer, Singapore, 2019.

[24] Liu, Yichuan, Hailey James, Otkrist Gupta, and Dan Raviv. "MRZ code extraction from visa and passport documents using convolutional neural networks." *International Journal on Document Analysis and Recognition (IJDAR)* (2021): 1-11.

[25] Chaudhuri, Arindam, Krupa Mandaviya, Pratixa Badelia, and Soumya K. Ghosh. "Optical character recognition systems." In *Optical Character Recognition Systems for Different Languages with Soft Computing*, pp. 9-41. Springer, Cham, 2017.

Chinese,[26] Japanese,[27] English,[28] Arabic,[29] Sanskrit,[30] Ancient Greek,[31] Coptic,[32] and Ancient Egyptian Hieroglyphic.[33] Although all such character recognition programs fall under the umbrella of OCR, many programs use completely different algorithms to better suit their data set. The programs can range from statistical clustering methods[34] to high level neural networks using machine learning.

The focus of OCR research is often on modern uses, such as the digitization of common documents to improve efficiency, and, thus, the important results of the work on these programs is typically limited to the identification of each character and how accurate and fast each program is. These are crucial results, but they are not the only information that can be gained from an OCR program. As mentioned above, any image recognition program will use its training on a data set to inform its decisions about an input. Directly or indirectly, this results in comparing the input character to the characters in the data set, often accompanied by a "similarity score", which is a number determined by the program that describes how similar two images are.[35] Although this is usually thought of as a means to the end of identification, the program's insights into the similarity of various characters can be used to learn more about the characters and the texts they came from. This is less important for modern material, but could be greatly useful when researching ancient material. Leveraging these similarity statistics provides a new way to look at ancient texts, allowing for complex comparisons to be made between characters, texts, handwritings both ancient and modern, locations, and time periods with more statistical power than has ever been possible before.

In the field of Egyptology, this method of looking at similarity scores to learn about ancient material has not been significantly attempted. However, that does not mean that OCR has been ignored in the field. There has been significant work already on using OCR on hieroglyphs,

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[26] Yu, Zhongda, Junyu Dong, Zhiqiang Wei, and Jianxiang Shen. "A fast image rotation algorithm for optical character recognition of Chinese documents." In *2006 International Conference on Communications, Circuits and Systems*, vol. 1, pp. 485-489. IEEE, 2006.

[27] Das, Soumendu, and Sreeparna Banerjee. "An algorithm for Japanese character recognition." *International Journal of Image, Graphics and Signal Processing* 7, no. 1 (2014): 9.

[28] Arica, Nafiz, and Fatos T. Yarman-Vural. "Optical character recognition for cursive handwriting." *IEEE transactions on pattern analysis and machine intelligence* 24, no. 6 (2002): 801-813.

[29] Cheung, Anthony, Mohammed Bennamoun, and Neil W. Bergmann. "An Arabic optical character recognition system using recognition-based segmentation." *Pattern recognition* 34, no. 2 (2001): 215-233.

[30] Avadesh, Meduri, and Navneet Goyal. "Optical character recognition for sanskrit using convolution neural networks." In *2018 13th IAPR International Workshop on Document Analysis Systems (DAS)*, pp. 447-452. IEEE, 2018.

[31] Robertson, Bruce, and Federico Boschetti. "Large-scale optical character recognition of ancient greek." *Mouseion* 14, no. 3 (2017): 341-359.

[32] Miyagawa, So, Kirill Bulert, Marco Büchler, and Heike Behlmer. "Optical character recognition of typeset Coptic text with neural networks." *Digital Scholarship in the Humanities* 34, no. Supplement_1 (2019): i135-i141.

[33] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).

[34] Romulus, Puja, Yan Maraden, Prima Dewi Purnamasari, and Anak Agung Putri Ratna. "An analysis of optical character recognition implementation for ancient Batak characters using K-nearest neighbors principle." In *2015 International Conference on Quality in Research (QiR)*, pp. 47-50. IEEE, 2015.

[35] Koch, Gregory, Richard Zemel, and Ruslan Salakhutdinov. "Siamese neural networks for one-shot image recognition." In *ICML deep learning workshop*, vol. 2. 2015.

a challenging problem due to the physical dissimilarity of hieroglyphs to most other writing systems. In 2013, Franken and van Gemert developed an OCR program to segment and identify hieroglyphs, using a large data set of almost 4000 annotated hieroglyphic characters from the pyramid of Unas.[36] Their program was able to identify each glyph based on five "image descriptors", taking into account shape (the frequency of edge pixels of each glyph and the correlation between the central cell and other cells), appearance (a Histogram of Oriented Gradients, i.e. edge gradient orientations), and mixtures of both and then comparing these metrics to the images in the data set. This method was adapted from prior work on Maya hieroglyph matching.[37] The final result was then improved using a language model that took into account hieroglyphs that are more likely to be next to one another, as in common words. This method resulted in an 83% correct detection of glyphs and an 85.5% correct identification of those successfully detected.

This work is, to my knowledge, the first foray into OCR for Egyptological material, producing successful results. Nevertheless, there are some limitations of the method used. First, the data set was quite limited, restricted to ten photographs of the walls of a single structure. This was a conscious choice by the authors to reduce variability, particularly in writing style. Unfortunately, this also means that their program would almost certainly be less accurate when applied to more varied material. In addition, this would impede any work attempting to use "similarity scores" to compare larger trends, since the location, time period, and author are all fixed for this one text. Of course, this was not a goal of theirs, so it is not necessarily a negative, but it is a limiting factor. Perhaps if one were to add to the data set, these questions could be better investigated. In 2018, Elnabawy *et al.* produced a similar work in segmenting and identifying hieroglyphic characters from images with similar, although not identical, methods.[38] This research was also limited in scope. Regrettably, neither paper offers open-source code or data sets, so the programs cannot be improved through the expansion of the data set and then used for comparisons. Beyond this, it is important to note that the methods used in these papers are tailored to images of hieroglyphs and likely would not be as useful when used for written work.

For written material, in 2015, Nederhof used OCR to digitize Sethe's Urkunden IV.[39,40] Urkunden IV is a collection of various ancient texts transcribed into handwritten hieroglyphs by Kurt Sethe. In Nederhof's paper, Sethe's individual handwritten characters are automatically detected by considering "blobs", defined as a connected set of black pixels. Then, each unknown glyph is compared to a set of "prototypes", a subset of the full data set of identified characters

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[36] Franken, Morris, and Jan C. van Gemert. "Automatic Egyptian hieroglyph recognition by retrieving images as texts." In *Proceedings of the 21st ACM international conference on Multimedia*, pp. 765-768. 2013.
[37] Frauel, Yann, Octavio Quesada, and Ernesto Bribiesca. "Detection of a polymorphic Mesoamerican symbol using a rule-based approach." *Pattern Recognition* 39, no. 7 (2006): 1380-1390.
[38] Elnabawy, Reham, Rimon Elias and Mohammed A.-M. Salem. "Image Based Hieroglyphic Character Recognition." In *2018 14th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS)* (2018): 32-39.
[39] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).
[40] Sethe, Kurt Heinrich. *Urkunden Der 18. Dynastie*. Leipzig: J. C. Hinrich, 1927.

that gives an approximation of the total variation. Prototypes were used to cut down on computational costs, given that it would be costly to compare each input to the whole data set. To further reduce these costs, Nederhof filtered the data set images by comparing each unknown by their aspect ratio and by frequencies computed using a Fast Fourier Transform (FFT). Then, an Image Distortion Model (IDM) was used to fully compare the sign to the filtered data set signs. Much of this method is used in my project, so a more in-depth discussion of the program's details is present in the "Methods" section of this paper. In short, the Image Distortion Model (IDM) results in a difference score (effectively the reverse of a similarity score) that is then used to determine the identity of each sign. This produced a high level of accuracy (91.3%). Through this method, Urkunden IV was able to be digitized and the program was made freely available, so, theoretically, the data set could be expanded and the program used for other applications.

Nederhof's research is unique in the field and it provides an excellent starting point for subsequent work. However, it is not without its limitations as well. Nederhof's focus on Sethe's Urkunden IV puts his tool's use firmly within recognizing handwritten transcriptions of ancient Egyptian, making it unable to be applied to the actual texts themselves. Furthermore, the employment of "prototypes", while useful in cutting down computational costs, would not be ideal when one wants to use the difference scores for large-scale morphological comparisons. This is because comparisons across texts, time periods, or locations would likely need a large amount of data to be significant. However, these types of comparisons are not even worth considering for Nederhof's data set, given that his program is looking at modern transcriptions and not the ancient material itself, nor morphologically accurate reproductions.

As has been described above, OCR has been used on images of hieroglyphs and on modern hieroglyphic transcriptions, but never on hieratic. This is chiefly due to the numerous additional problems hieratic poses compared to hieroglyphs. First, hieratic characters are often not distinct from one another and can be ligatured together or can be overlapping. This can cause problems even for a human analysis of a text, necessitating the use of context clues. Although it is sometimes easy for humans to mentally separate two signs or recognize a ligature, it is far more difficult for a program to do so. Nederhof mentions in the end of his paper that the touching of hieratic signs poses a problem to his blob-based automatic detection.[41] Both hieroglyphs and written transcriptions rarely have this problem. Second, many hieratic characters look nearly identical to one another. This is true for some characters in Urkunden IV, but not nearly to the same degree as in hieratic. Third, hieratic can be far more variable than hieroglyphs, with multiple ways of writing the same sign being present even in the same text. Möller showed the immense range of this in his paleography.[42] This element of hieratic makes it particularly apt for morphological comparisons across space and time, but also leads to difficulties in automatic recognition. Relatedly, hieratic can be written vertically or horizontally, further increasing variation. While this is also true for hieroglyphs, the change in orientation does not usually affect

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[41] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).
[42] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1

the form of the hieroglyphic signs. Hieratic, on the other hand, has different ligatures and overlaps depending on whether the signs are written next to one another or on top of one another.

All of these problems are solvable with a large data set. A data set that is sufficiently large would provide the training necessary for an algorithm to identify ligatured characters and even perhaps separate overlapping ones. It would also allow a sufficiently powerful algorithm to distinguish between similar characters, possibly with even greater accuracy than a person could. Lastly, it would capture close to the full variation of hieratic and make sure few signs go unrecognized. Cursive scripts that are somewhat visually similar to hieratic, such as Urdu with its ligatures and overlaps, have been shown to work with OCR methods and large data sets.[43] However, no such data set existed for hieratic before this paper. There are currently available digital paleographies, such as the Hieratische Paläographie DB which is based on Möller's work, but they do not have enough different versions of each character for accurate OCR and are not intended for that purpose.[44]

Even with a sufficient data set, there are a number of pitfalls and limitations of using OCR on hieratic that must be avoided or at least acknowledged. For instance, to accurately identify hieratic characters at the moment, one needs to use facsimiles because the variations in the damage of the material, the ink darkness, and image quality would likely be too much for any image recognition software, especially on top of all of the other variations present in hieratic. It is not unusual to try and remove unhelpful variation before using a data set for OCR; Nederhof made Sethe's glyphs purely black and white for his OCR program and Franken and van Gemert used black and white images of the hieroglyphs in the pyramid of Unas.[45,46] One could argue that, rather than use a facsimile, one should try and just color the hieratic images so the glyphs are purely black and the background is purely white, but doing so would effectively be creating a facsimile. Because facsimiles are being used, some data will necessarily be lost and, while this is good because one wants to lose some of the aforementioned negative variation, it could also be dangerous because a facsimile maker could unwittingly lose an important part of the variation. This process of making a facsimile is subject to human decision making and, thus, human error. Facsimile use also introduces variation because using facsimiles made by two different people could result in differences being detected due to the facsimile maker, not the original, underlying hieratic. However, using facsimiles is the only practical choice without the presence of an impossibly large data set. In addition, some of these potential issues with facsimiles can be monitored. For example, if glyphs from one facsimile maker are shown to be more similar to each other, regardless of which text they are from, rather than showing similarities to ones from

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[43] Naz, Saeeda, Khizar Hayat, Muhammad Imran Razzak, Muhammad Waqas Anwar, Sajjad A. Madani, and Samee U. Khan. "The optical character recognition of Urdu-like cursive scripts." *Pattern Recognition* 47, no. 3 (2014): 1229-1248.

[44] Nagai, Masakatsu, Waki, Toshihito, Takahashi, Yona, and Nakamura, Satoru. *Hieratische Paläographie DB*. Tsukuba University. January 31, 2021. https://moeller.jinsha.tsukuba.ac.jp.

[45] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).

[46] Franken, Morris, and Jan C. van Gemert. "Automatic Egyptian hieroglyph recognition by retrieving images as texts." In *Proceedings of the 21st ACM international conference on Multimedia*, pp. 765-768. 2013.

their same original text by a different facsimile maker, that would raise some red flags regarding this modern influence.

It is known that the bigger the data set is, the more accurate an OCR program will be. However, there should be a rough threshold for when the data set is large enough to be at least reasonably accurate. For a script like hieratic, to which no one has ever applied OCR before, this threshold is unknown. If one creates a program with too small a data set, they risk wasting time trying to optimize a program that simply cannot be optimized, given the data. If one creates too large a data set, they risk overshooting the threshold and spending time adding effectively redundant glyphs that will not meaningfully improve program performance. Of these two outcomes, it is far better to overshoot than undershoot when creating a data set. Because of this, as many texts as possible within the time frame of this project were considered, in order to overshoot the data set size.

Background

Due to the number of texts whose facsimiles are the basis for this project's data set, a brief discussion of each will be provided.[47] In addition, Table 2, provided below, contains succinct information about each of the original texts. This table includes the text's common name, the accepted name of the papyrus, the creator of the facsimile, the genre of the text, the approximate date of the text, the origin (provenance) of the text, if known, and how many signs from the text appear in the data set. The genre column has been filled out purely based on modern conceptions of the texts. It should be noted that the ancient Egyptians may not have envisioned these genre distinctions in the same way or even at all. Before going into the texts, some further background will be supplied, including history and common questions asked about ancient texts.

History

The original texts that make up the data set for the program all date from around the ancient Egyptian Middle Kingdom, particularly the Twelfth Dynasty, or slightly after. To provide context, a brief history of the Middle Kingdom and the eras surrounding it will follow. Prior to the Middle Kingdom, during the First Intermediate Period, Egypt saw a span of fragmented government.[48] Two series of local rulers, one from Thebes in the South and the other from Herakleopolis Magna in the North, vied for control of Egypt. The Middle Kingdom was created when king Mentuhotep II of Thebes reunited Egypt through conquest.[49] Mentuhotep II was in the line of rulers now referred to as the Eleventh Dynasty. Nineteen years after Mentuhotep II's death, the Eleventh Dynasty ended and Amenemhat I rose to power, beginning the Twelfth Dynasty. Amenemhat I moved the capital of the kingdom from Thebes to Itjtawy, a more northern location. During this prosperous period of Egyptian history, the central bureaucracy expanded, foreign conquests increased, and large-scale projects like the irrigation of the Faiyum were undertaken. However, this stability did not last. The Thirteenth Dynasty, consisting of many ephemeral rulers, moved the capital back to Thebes as the region began fragmenting once again. Soon, the Middle Kingdom had collapsed and the Second Intermediate Period had begun. The Second Intermediate Period was characterized by multiple lineages of local rulers again fighting for power over Egypt.[50] In the north, the Fifteenth Dynasty ruled at Avaris, made up of foreign Hyksos kings. In the south, kings of the Theban region ruled. Egypt was united once again by Theban king Ahmose of the Eighteenth Dynasty, beginning the New Kingdom.

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[47] It is worth noting that, when I write "data set", I do not mean the raw data (i.e. the primary sources), I mean the data set that is input into the OCR program, which was created from primary sources discussed in this section, through the accompanying methods discussed in the next section.

[48] Seidlmayer, Stephan. "The First Intermediate Period." Essay. In *Oxford History of Ancient Egypt*, edited by Ian Shaw, 118–47. Oxford: Oxford University, 2000.

[49] Callender, Gae. "The Middle Kingdom Renaissance." Essay. In *Oxford History of Ancient Egypt*, edited by Ian Shaw, 148–83. Oxford: Oxford University, 2000.

[50] Bourriau, Janine. "The Second Intermediate Period." Essay. In *Oxford History of Ancient Egypt*, edited by Ian Shaw, 118–47. Oxford: Oxford University, 2000.

Table 1 (shown below) shows one version of Egyptian chronology, including dates, so a reader unfamiliar with Egyptian history can get a better sense of the timeline. This information is taken from Shaw (2000).[51] One should be aware that there is plenty of debate about many aspects of the chronology, especially the exact dates, and a fair number of the scholars cited in this work may disagree with some parts of this timeline. The timeline is not meant to be a comprehensive review of the literature, just a tool to place the rest of the discussion in context. It is also worth noting that some of the dynasties ran concurrently, especially in the Intermediate Periods. Dynasties that did not rule all of Egypt have their capital location in parentheses. The timeline includes more information about the Middle Kingdom, given the focus of this paper.

Table 1: A timeline and chronology of ancient Egyptian history, adapted from Shaw (2000)

Period	Dynasty	Ruler	Date
Predynastic	NA - Dynasty 0	NA - Narmer	c. 5300 - 3000 BCE
Early Dynastic	First - Second	Aha - Khasekhemwy	c. 3000 - 2686 BCE
Old Kingdom	Third - Eighth	Nebka - Neferirkare?	2686 - 2160 BCE
First Intermediate	Ninth - Tenth (Herakleopolis)	Khety - Merykara	2160 - 2025 BCE
	Eleventh (Thebes)	Mentuhotep I - Intef III	2125 - 2055 BCE
Middle Kingdom	Eleventh	Mentuhotep II	2055 - 2004 BCE
		Mentuhotep III	2004 - 1992 BCE
		Mentuhotep IV	1992 - 1985 BCE
	Twelfth	Amenemhat I	1985 - 1956 BCE
		Senwosret I	1956 - 1911 BCE
		Amenemhat II	1911 - 1877 BCE
		Senwosret II	1877 - 1870 BCE
		Senwosret III	1870-1831 BCE
		Amenemhat III	1831 - 1786 BCE
		Amenemhat IV	1786 - 1777 BCE
		Sobekneferu	1777 - 1773 BCE

[51] Shaw, Ian, ed. *The Oxford History of Ancient Egypt*. Oxford University Press, 2000.

	Thirteenth	Wegaf - Ay	1773 - after 1650 BCE
	Fourteenth	Minor rulers, possibly overlapping with the Thirteenth or Fifteenth Dynasties	1773 - 1650 BCE
Second Intermediate	Fifteenth (Avaris)	Salitis - Khamudi	1650 - 1550 BCE
	Sixteenth - Seventeenth (Thebes)	Minor ruler - Kamose	1650-1550 BCE
New Kingdom	Eighteenth - Twentieth	Ahmose - Rameses XI	1550-1069 BCE
Third Intermediate	Twenty-first - Twenty-fifth	Smendes - Tantamani	1069 - 664 BCE
Late	Twenty-sixth - Thirtieth	Nekau I - Darius III Codoman	664 - 332 BCE
Ptolemaic	Macedonian - Ptolemaic	Alexander the Great - Ptolemy XV Caesarion	332 - 30 BCE
Roman	Roman Emperors	Augustus - Eugenius	30 BCE - 395 CE

The Middle Kingdom expanded the Old Kingdom system of government, creating a complex administrative, diplomatic, and military system.[52] To support the massive bureaucracy needed for the running of the kingdom, the already existing hieratic (cursive hieroglyphic) script was expanded in use.[53] Hieratic, first known from the Predynastic period, was used on papyrus as early as the First Dynasty. The earliest hieratic signs strongly resemble hieroglyphs, the oldest Egyptian script used for stone inscriptions, but diverged shortly after. Hieratic was used in the Old Kingdom, but, in the Middle Kingdom, it began being used to a far greater extent, recording literary and administrative texts, as well as letters and numerous other documents. During this time, hieroglyphs were still used for official stone inscriptions. Before the Twelfth Dynasty, hieratic was mainly written in vertical columns, but horizontal rows became the standard during and after that period.[54] The script is always written from right to left, regardless of the orientation.

[52] Callender, Gae. "The Middle Kingdom Renaissance." Essay. In *Oxford History of Ancient Egypt*, edited by Ian Shaw, 148–83. Oxford: Oxford University, 2000.
[53] Redford, Donald B, and Edward F Wente. "Hieratic." Essay. In *The Oxford Encyclopedia of Ancient Egypt*. P-Z 3, 3:206–10. Oxford University Press, 2001.
[54] Ikram, Salima. "Hieratic." Essay. In *The Encyclopedia of Ancient History Ge-In 6*, 3207-8, edited by Roger S. Bagnall, Kai Brodersen, Craige Brian Champion, Andrew Erskine, and Sabine R. Huebner, Vol. 6. Oxford: Wiley-Blackwell, 2013.

It is important to note that some scholars believe that hieratic was actually first developed in the Middle Kingdom for the expanding bureaucracy and the earlier material written in ink is not hieratic, but rather "cursive hieroglyphs".[55] These "cursive hieroglyphs" differ from hieratic, which is also often called a cursive form of hieroglyphs, in that "cursive hieroglyphs" are far more angular and have many fewer ligatures. In later periods, it is clear that "cursive hieroglyphs" and hieratic were both used. For example, even when hieratic was widely adopted, "cursive hieroglyphs" were still used to write the Book of the Dead.[56] Because language and writing generally develop slowly over time, there is no obvious point to which one can point where hieratic first arose or split from cursive hieroglyphic. Thus, the origins of hieratic are still in contention. However, it is not in contention that, by the Middle Kingdom, hieratic was the dominant form of the script for writing on papyrus.

Hieratic papyri have been found all over Egypt, but some areas have yielded an abundance. One such site is Lahun, a Middle Kingdom pyramid town related to king Senwoseret II's funerary cult.[57] The town was built around 1895 BCE in the Faiyum region of Egypt, in the North.[58] Many workers for the king and their families lived at this location, producing a wealth of texts by way of letters, religious rituals, medical writings, and administrative/legal documents. Lahun was likely near the Twelfth Dynasty capital of Itjtawy, but Itjtawy has never been securely located.[59] Beyond the Lahun material, a great wealth of Middle Kingdom hieratic texts have been found in Theban tombs. Thebes continued to be prominent even after the capital was moved. Thus, there is extant material from or near both of the major political centers in the Middle Kingdom, in the north and the south. Other papyri have been found at numerous other sites as well. Hieratic graffiti, carved in stone, not on papyrus, has also been found in rock quarries. There have also been lots of hieratic writings found on ostraca (potsherds). In this paper, ostraca were not considered, in order to limit the variation in the data set. Some texts, like a lot of wisdom literature, have only been found on ostraca, making this a notable limitation.[60]

Hieratic Questions

When working with ancient papyri, there are a number of fundamental questions that researchers ask. The first of these is often "where is the text from?". This question is important because a text cannot be placed into its proper context if its location is unknown. For instance, a Second Intermediate Period text about a won battle would have a very different historical

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[55] Dr. Brian Muhs (Associate Professor of Egyptology, University of Chicago) in discussion with the author, March 2022.

[56] Lucarelli, Rita. "Cursive Hieroglyphs in the Book of the Dead." In *The Oxford Handbook of Egyptian Epigraphy and Paleography*. 2020.

[57] Callender, Gae. "The Middle Kingdom Renaissance." Essay. In *Oxford History of Ancient Egypt*, edited by Ian Shaw, 148–83. Oxford: Oxford University, 2000.

[58] David, A.R. "Lahun, town." Essay. In *Encyclopedia of the Archaeology of Ancient Egypt*, edited by Kathryn A. Bard and Steven Blake Shubert, 430–2. London: Routledge, 1999.

[59] Malleson, Claire. "Investigating Ancient Egyptian Towns: A Case Study of Itj-tawy." In *Current Research in Egyptology 2005: Proceedings of the Sixth Annual Symposium which Took Place at the University of Cambridge, 6-8 January 2005*, vol. 909, p. 90. Oxbow Books Limited, 2007.

[60] Hagen, Fredrik. *An ancient Egyptian literary text in context: the instruction of Ptahhotep*. Peeters, 2012.

implication if it was from Thebes or Avaris. If the findspot of a text has been adequately recorded, this provenance question is answered easily and this is the case for many texts; tautologically, such texts are from where they were found. However, this is not always the case. Sometimes texts were rediscovered by scholars without their findspot being recorded and sometimes they were bought secondhand without concrete information from the seller about their original whereabouts. Whatever the reason may be, the provenance of texts is not always a trivial matter. Therefore, researchers use textual clues, such as place names or known individuals, paleography, and archeological methods to try and estimate a text's origin. It should be noted that where a text was found is not necessarily where a text was originally written, although the two are often related. This is a limitation of history that must be accepted for the time being. Perhaps as comparative paleographic methods increase in scope through technology, scholars will eventually be able to locate a text's original place of writing, regardless of its findspot, but this is far in the future.

Another question often asked about papyri is "when was the text written?" and the similar "when was the text composed?". These two distinct questions are also vital for placing a text in context. Even knowing the general period or dynasty of a text can provide insight into the thoughts of the time, whereas the exact date of a text can even help establish a chronology. The date of composition (i.e. when a text was originally created) can be useful, but it is often quite hard to establish. The date that a version of the text (i.e. a single papyrus) was written can greatly assist with this, but it is by no means a perfect metric. In addition, the date a text on a single papyrus was written is, in and of itself, a difficult thing to establish. The most common way of dating a text on its own, apart from dating by association with other items in its findspot, is by paleography. However, dating a text by paleography comes with challenges. The great variety of hieratic within and between texts has made human-based paleographic approaches always limited and uncertain.[61] Of course, these studies have been immensely useful to the field and have provided a wealth of information, but they do have constraints on how much they can say.

Beyond the "where" and "when" of texts, scholars also frequently ask who wrote the text. Sometimes the author of a text is listed when the scribe signed their name, as is true for the Rhind Mathematical Papyrus.[62] Despite this, the essential context of the circumstances surrounding the scribe's life is almost always a mystery. Especially for most of the larger literary texts, the scribes remain completely anonymous.[63] Even without the name, features of a specific scribe's writing can be distinguished, from idiosyncrasies of their handwriting to words they spell in a unique way. In this manner, different texts can sometimes be attributed to the same scribe, even without knowledge of the specific scribe or their life. Although insights can be gained from the way a scribe of a copy writes, the original composer or composers of a text are overwhelmingly out of reach.

[61] Parkinson, Richard B. *Poetry and Culture in Middle Kingdom Egypt: A Dark Side to Perfection*. London: Equinox Publ, 2002.
[62] Chace, Arnold B. *The Rhind Mathematical Papyrus*. Oberlin, OH: Mathematical Association of America, 1927.
[63] Parkinson, Richard B. *Reading ancient Egyptian poetry: among other histories*. John Wiley & Sons, 2009.

As for why a text was written, clues to this can be gained by the content of the text, including the themes, plot, and especially the genre. The genres modern readers place on ancient texts are frequently modern inventions.[64] As mentioned above, there is usually little evidence to suggest that the ancient writers and readers of a text considered it one genre or the other, although there are cases where an ancient genre category is clear, such as ancient Egyptian "wisdom/instruction" literature.[65] Even if the genre is determined, the purpose of a text is still often up to interpretation.

The Texts

The Story of the Shipwrecked Sailor (P. Hermitage 1115) is a literary text that has been dated to a bit after 2000 BCE, placing it in the Middle Kingdom around the beginning of the Twelfth Dynasty.[66] This is generally accepted, although some have argued for a slightly earlier Eleventh Dynasty date.[67] The text was found by Wladimir Golénischeff in 1881 in a museum cabinet. Therefore, its original provenance is unknown.[68] However, it has been theorized to have come from Thebes based on similarities noted between its handwriting and that of Papyrus Prisse.[69] The complex text consists of multiple frame stories written as if they were told in an oral manner, mainly describing an unnamed sailor's journey through being shipwrecked, marooned on an island, meeting a mystical serpent, and then being rescued.[70] The text can be broken up into individual chapters and units, based on "semantic recurrences", far beyond the more obvious couplets. The chapters have been shown to be remarkably symmetrical.[71] These factors, along with patterned postponing and tense-neutral clauses, has led the story to be described as written in verse, rather than prose.[72] The content of the text reveals no simple interpretation, although themes of lessons of experience,[73] love of family, and the capability of Egyptians abroad and under stress have all been discussed.[74] The themes in the story make sense with the hypothesized dating near the beginning of the Middle Kingdom, as they seem to express

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[64] Parkinson, Richard B. *Poetry and Culture in Middle Kingdom Egypt: A Dark Side to Perfection*. London: Equinox Publ, 2002.
[65] Simpson, William Kelly. *The Literature of Ancient Egypt.* Yale University Press, 2003.
[66] Simpson, William Kelly. *The Literature of Ancient Egypt.* Yale University Press, 2003.
[67] Kurth, Dieter. "Zur Interpretation der Geschichte des Schiffbrüchigen." *Studien zur altägyptischen Kultur* 14 (1987): 167-179.
[68] Golénischeff, W. *Les Papyrus Hieratiques No 1115, 1116A et 1116B de l'Ermitage Imperial a St Petersbourg*. St Petersburg: Ermitage Imperial, 1913.
[69] von Bomhard, Anne-Sophie. "Le conte du naufragé et le papyrus Prisse." *Revue d'Égyptologie* 50 (1999): 51-65.
[70] Baines, John. "Interpreting the Story of the Shipwrecked Sailor." *The Journal of Egyptian Archaeology* 76, no. 1 (1990): 55-72.
[71] Burkard, Günter. *Überlegungen zur Form der ägyptischen Literatur: die Geschichte des Schiffbrüchigen als literarisches Kunstwerk*. Harrassowitz, 1993.
[72] Foster, John L. ""The Shipwrecked Sailor": Prose or Verse? (Postponing Clauses and Tense-neutral Clauses)." *Studien zur altägyptischen Kultur* 15 (1988): 69-109.
[73] Baines, John. "Interpreting the Story of the Shipwrecked Sailor." *The Journal of Egyptian Archaeology* 76, no. 1 (1990): 55-72.
[74] Simpson, William Kelly. *The Literature of Ancient Egypt.* Yale University Press, 2003.

some form of unrest lingering from the First Intermediate Period.[75] A fairly comprehensive history of thoughts on the Shipwrecked Sailor, from its religious symbolism[76] to its didactic nature, is given in Kurth (1987).[77]

The Eloquent Peasant (B1: P. Berlin 3023, R: P. Ramesseum A) is also a literary text. Its composition has been dated to the mid-late Twelfth Dynasty in the Middle Kingdom, although it is set in the First Intermediate Period in the Ninth or Tenth Dynasty, evident by its Heracleopolitan setting.[78,79] The scholarly consensus has largely converged on the Twelfth Dynasty dating for the composition, especially given that the title of "chief steward", common in the story, is only known from the Twelfth Dynasty and onward.[80] Tentatively, the reign of Amenemhat III has been implicated as a possible more specific dating.[81] However, some have disagreed, dating the text to the First Intermediate Period, given the supposed unlikelihood of a later text being attributed to the reign of a First Intermediate Period king (Nebkaure Khety).[82] The B1 text was discovered in a tomb library in Thebes around 1830 CE and the R text was excavated in a chest with other papyri in a tomb in the Ramesseum in Thebes around 1898 CE.[83] The B1 and R copies have been reliably dated to the Twelfth and Thirteenth Dynasties respectively.[84] Given the texts and magical items found in the Ramesseum tomb, the tomb has been hypothesized to have belonged to a lector priest. The text, a mix of narrative and poetic elements, relates the story of a peasant who has his property unfairly stolen from him and poetically petitions the chief steward of the crown to help him. The peasant's speeches deal with the important Egyptian concept of Ma'at (order/truth/justice). In addition to this theme, the text deals with oratory forms, irony, the imperfectness of speech,[85] the legal system, and corruption.[86]

The Story of Sinuhe (B: P. Berlin 3022, R: P. Ramesseum A) is a literary text with two copies dated to the Twelfth and Thirteenth Dynasties respectively that together fill in almost the

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[75] Kurth, Dieter. "Zur Interpretation der Geschichte des Schiffbrüchigen." *Studien zur altägyptischen Kultur* 14 (1987): 167-179.
[76] Derchain-Urtel, Maria Theresia. "Die Schlange des "Schiffbrüchigen". *Studien zur altägyptischen Kultur* 1 (1974): 83-104.
[77] Kurth, Dieter. "Zur Interpretation der Geschichte des Schiffbrüchigen." *Studien zur altägyptischen Kultur* 14 (1987): 167-179.
[78] Parkinson, Richard B. "The Date of the 'Tale of the Eloquent Peasant'." *Revue d'Egyptologie* 42 (1991): 171-181.
[79] Simpson, William Kelly. *The Literature of Ancient Egypt.* Yale University Press, 2003.
[80] Berlev, Oleg D., Jürgen Osing, and Gerhard Fecht. "The Date of the "Eloquent Peasant"". *Form und Mass: Beiträge zur Literatur, Sprache und Kunst des alten Ägypten: Festschrift für Gerhard Fecht* (1987): 78-83.
[81] Parkinson, Richard B. *Reading ancient Egyptian poetry: among other histories*. John Wiley & Sons, 2009.
[82] Brunner, Hellmut. *Altägyptische Weisheit: Lehren für das Leben*. Zurich und Munchen: Artemis Verlag, 1989.
[83] Parkinson, Richard B. and Baylis, Lisa. *Four 12th Dynasty Literary Papyri (Pap. Berlin P. 3022-5): A Photographic Record*. Berlin: Akademie Verlag, 2012.
[84] Parkinson, Richard B. *Voices from Ancient Egypt: an anthology of Middle Kingdom writings*. British Museum, 1991.
[85] Parkinson, Richard B. "Literary form and the Tale of the Eloquent Peasant." *The Journal of Egyptian Archaeology* 78, no. 1 (1992): 163-178.
[86] Shupak, Nili. "A New Source for the Study of the Judiciary and Law of Ancient Egypt: "The Tale of the Eloquent Peasant"." *Journal of Near Eastern Studies* 51, no. 1 (1992): 1-18.

entire text.[87] These dates are reasonably agreed upon in the literature.[88] Parkinson estimates the original composition to have been just after Senwosret I's reign.[89] It is clear that the text cannot date earlier than the Twelfth Dynasty because the story begins with the death of Amenemhet I, the founder of the Twelfth Dynasty. The B text was discovered in the same tomb in Thebes as the Eloquent Peasant's B1 text around 1830 CE and the R text was found in the Ramesseum in Thebes around 1898 CE on the other side of the same papyrus as the Eloquent Peasant's R text.[90] The Sinuhe B text has been demonstrated to be written by the same scribe as the Eloquent Peasant B1 text and, likewise, the two R texts have been shown to be in the same hand. Written in a first-person journal style, the story describes the adventures of the titular Sinuhe after he flees once the king's death is known. Sinuhe spends time in the area of Syria and Palestine and eventually returns to Egypt. Despite the story seeming reasonably plausible, there has never been any trace of a real Sinuhe found. The text deals with similar themes to other compositions: Egyptians abroad, a love of home, a loyalty to Egypt, and foreign relations. In addition, when the story is divided into "chapters", there is a striking symmetricality, much like what was described for the Shipwrecked Sailor.[91] On top of this, the text has been shown to have literary and syntactic similarities to other texts written in verse, such as The Hymn to the Nile. Thus, the Story of Sinuhe has been placed in the genre of "narrative verse".[92]

The Maxims of Ptahhotep (P. Prisse) has a slight literary character, but should be placed in the Egyptian genre of "wisdom" or "instruction" literature.[93] It consists of a set of maxims to guide one's conduct by, supposedly said by an Old Kingdom Fifth Dynasty vizier named Ptahhotep to his son. Although the text is set in the Old Kingdom and attempts to use some grammatical constructions from Old Egyptian, it seems more likely to most scholars that the text was originally composed in the Middle Kingdom. P. Prisse is the only copy of the text that is complete and it is also likely the earliest extant copy; this copy specifically has been dated to the Middle Kingdom. This dating is by consensus: paleographic methods have placed the text in the late Eleventh Dynasty or the early Twelfth Dynasty, orthographic methods have placed the text in the late Twelfth Dynasty, and archaeological methods have placed the text in the Eleventh or Twelfth Dynasties (although dating this text based on the archaeological conditions of its findspot is problematic, as will be discussed).[94] Overall, most recent scholarship has placed

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[87] Simpson, William Kelly. *The Literature of Ancient Egypt.* Yale University Press, 2003.

[88] Parkinson, Richard B. *Voices from Ancient Egypt: an anthology of Middle Kingdom writings*. British Museum, 1991.

[89] Parkinson, Richard B. *The Tale of Sinuhe and Other Ancient Egyptian Poems 1940-1640 BC*. Oxford University Press, 1997.

[90] Parkinson, Richard B. and Baylis, Lisa. *Four 12th Dynasty Literary Papyri (Pap. Berlin P. 3022-5): A Photographic Record*. Berlin: Akademie Verlag, 2012.

[91] Burkard, Günter. *Überlegungen zur Form der ägyptischen Literatur: die Geschichte des Schiffbrüchigen als literarisches Kunstwerk*. Harrassowitz, 1993.

[92] Foster, John L. "Sinuhé: The Ancient Egyptian genre of narrative verse." *Journal of Near Eastern Studies* 39, no. 2 (1980): 89-117.

[93] Simpson, William Kelly. *The Literature of Ancient Egypt*. Yale University Press, 2003.

[94] Dewachter, Michel. "Nouvelles informations relatives à l'exploitation de la nécropole royale de Drah Aboul Neggah." *Revue d'Égyptologie* 36 (1985): 43-66.

Papyrus Prisse in the mid-late Twelfth Dynasty.[95] The text was bought by Émile Prisse d'Avennes from a worker in Cairo during his excavations of the Theban necropolis.[96] The text's general provenance has been taken as the Theban area, most likely in Dra' Abu el-Naga'. This claim makes sense, given that many Theban texts were sold in Cairo.[97] However, some have called the finding narrative into question, rightfully pointing out that the exact place from which Prisse hypothesized the text to have originated had not yet been discovered or excavated when he acquired the papyrus.[98] Nevertheless, the Theban necropolis is still statistically and historically the most likely findspot, despite the specific location within the necropolis being unknown.[99] The text has underlying themes of morality and Ma'at, but serves primarily as a practical instruction. The text has also been shown to be written in a style most commonly associated with texts in verse (the "thought couplet").[100] It should be noted that Papyrus Prisse also contains a section from the Instructions of Kagemni, another wisdom text. However, this is not dealt with in this paper because none of the sections from Möller's facsimile of the papyrus contain parts of the Instructions of Kagemni. A comprehensive history of publications about the Maxims of Ptahhotep is given in Hagen (2012).[101]

Papyrus Westcar (P. Berlin 3033), also known as "King Cheops and the Magicians", is a literary text set in the reign of Khufu of the Fourth Dynasty of the Old Kingdom.[102] Despite the early setting, the papyrus, the only known copy of the text, has been dated to the Eighteenth Dynasty and its composition has been dated to the Twelfth Dynasty. While the composition date seems largely agreed upon, some, such as Goedicke, have gone against the grain, using historical and textual analysis to argue for a later composition date.[103] In addition, the papyrus's date of writing has sometimes been described as somewhere in the Second Intermediate Period, rather than the Eighteenth Dynasty New Kingdom date.[104] This Second Intermediate Period date has been supported by analysis of paleography and line format.[105,106] Erman noted the similarities of the language used in the text with that of the Rhind Papyrus, from the Hyksos period, as well as

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[95] Simpson, William Kelly. *The Literature of Ancient Egypt*. Yale University Press, 2003.
[96] Jéquier Gustave. *Le Papyrus Prisse Et Ses Variantes: Papyrus De La Bibliothèque Nationale (Nos 183 à 194), Papyrus 10371 ET 10435 Du British Museum, Tablette Carnarvon Au Musée Du Caire: Publiés En Fac-similé (16 Planches En Phototypie)*. Paris: Librairie Paul Geuthner, 1911.
[97] Hagen, Fredrik. *An ancient Egyptian literary text in context: the instruction of Ptahhotep*. Peeters, 2012.
[98] Dewachter, Michel. "Nouvelles informations relatives à l'exploitation de la nécropole royale de Drah Aboul Neggah." *Revue d'Égyptologie* 36 (1985): 43-66.
[99] Quirke, Stephen. *Egyptian literature 1800 BC: questions and readings*. London: Golden House, 2004.
[100] Foster, John L. *Thought couplets and clause sequences in a literary text: the maxims of Ptah-hotep*. Toronto: Society for the Study of Egyptian Antiquities, 1977.
[101] Hagen, Fredrik. *An ancient Egyptian literary text in context: the instruction of Ptahhotep*. Peeters, 2012.
[102] Simpson, William Kelly. *The Literature of Ancient Egypt.* Yale University Press, 2003.
[103] Goedicke, Hans. "Thoughts about the Papyrus Westcar." *Zeitschrift für ägyptische Sprache und Altertumskunde* 120, no. 1 (1993): 23-36.
[104] Redford, Donald B, and Richard B Parkinson. "Papyrus Westcar." Essay. In *The Oxford Encyclopedia of Ancient Egypt*. P-Z 3, 3:24–25. Oxford University Press, 2001.
[105] Goedicke, Hans. "Thoughts about the Papyrus Westcar." *Zeitschrift für ägyptische Sprache und Altertumskunde* 120, no. 1 (1993): 23-36.
[106] Cerný, Jaroslav. *Paper and Books in Ancient Egypt. An inaugural lecture delivered at University College London, 29 May 1947*. Ares Publ., 1952.

that of Papyrus Ebers, from the New Kingdom, leaving the question unanswered.[107] The story uses historical figures as characters, but it seems likely that it was not written with historicity as its main intent.[108] The circumstances of the papyrus's discovery are unknown, and thus, its provenance is unknown.[109] It was bought from Henry Westcar in 1938/39 CE by Richard Lepsius.[110] Through a series of magical tales, for which the beginning and ending have been lost, the story offers an explanation for the end of Khufu's lineage and the start of the Fifth Dynasty. The story deals with elements of prophecy, kingship, and even political satire. Like many other literary texts cited here, this story has been thought of as metrical verse, rather than prose.[111]

The Hymn to Senwosret III (UC 32157) is a "literary religious" text, dated to the reign of Senwosret III, a pharaoh of the Twelfth Dynasty of the Middle Kingdom.[112] This dating is very clear, given the subject matter of the text. Much like the other Lahun material, it was discovered in the ancient town of Lahun in Faiyum, Egypt by Flinders Petrie in 1889 CE.[113] The hymn may have been recited during rituals of the royal cult or on occasions of a visit by the king.[114,115] The text contains six parts, but only the first four are well preserved.[116] The text poetically praises Senwosret III, using metaphor to convey themes of kingship and of the king as the protector of the land. The text is visually in meter, with indented lines and frequent repetition.

The Lahun Temple Files (P. Berlin 10003) are pieces of an administrative document from the temple of Senwosret II in the town of Lahun.[117] They were found after Petrie's excavations at the town by Ludwig Borchardt. The files can be dated to the Twelfth Dynasty of the Middle Kingdom. Like the other Lahun papyri, the dating and especially the findspot are not much contested in the literature. The temple files are one homogenous archive, only dealing with life within the temple, both accounts and who was on duty.[118] The specific sections of the archive used in this paper contain a report of one phyle of the temple priesthood taking over from

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[107] Erman, Adolf. *Die sprache des papyrus Westcar*. Göttingen: Dieterich'sche Verlagsbuchhandlung, 1889.
[108] Hays, Harold M. "The Historicity of Papyrus Westcar." *Zeitschrift für ägyptische Sprache und Altertumskunde* 129, no. 1 (2002): 20-30.
[109] Erman, Adolf. *Die Märchen Des Papyrus Westcar: I: Einleitung Und Kommentar. II: Glossar, Palaeographische Bemerkungen Und Feststellung Des Textes*. Berlin: Spemann, 1890.
[110] Goedicke, Hans. "Thoughts about the Papyrus Westcar." *Zeitschrift für ägyptische Sprache und Altertumskunde* 120, no. 1 (1993): 23-36.
[111] Redford, Donald B, and Richard B Parkinson. "Papyrus Westcar." Essay. In *The Oxford Encyclopedia of Ancient Egypt*. P-Z 3, 3:24–25. Oxford University Press, 2001.
[112] Collier, Mark and Quirke, Stephen. *The UCL Lahun Papyri: Religious, Literary, Legal, Mathematical and Medical*. BAR International Series 1209. Oxford: Archaeopress, 2004.
[113] Quirke, Stephen. "A preliminary study of technical terms in accounts of the Illahun temple archive." *Ägypten und Levante/Egypt and the Levant* 7 (1998): 9-16.
[114] Parkinson, Richard B. *Voices from Ancient Egypt: an anthology of Middle Kingdom writings*. British Museum, 1991.
[115] Lichtheim, Miriam. *Ancient Egyptian literature: a book of readings*. Vol. 1. Berkeley: University of California Press, 1973.
[116] Simpson, William Kelly. *The Literature of Ancient Egypt.* Yale University Press, 2003.
[117] Quirke, Stephen. "A preliminary study of technical terms in accounts of the Illahun temple archive." *Ägypten und Levante/Egypt and the Levant* 7 (1998): 9-16.
[118] Quirke, Stephen. *The administration of Egypt in the Late Middle Kingdom: the hieratic documents*. New Malden [Surrey]: SIA publ., 1990.

another and certifying the temple inventory.[119]

The Will of Wah (UC 32058) is also an administrative document from the town of Lahun, dated to the Twelfth Dynasty of the Middle Kingdom, and found after Petrie's excavations.[120] The Will includes a regnal date of Year 2 after a Year 44. Based on reign length, Amenemhat III must be the king indicated in Year 44 and, thus, the king indicated by Year 2 is likely Amenemhat IV.[121,122] This would place the Will as being written quite late in the Twelfth Dynasty. The text is a legal will made for a priest named Wah, transferring his property to his wife upon his death and setting up a plan for his burial. The text includes a copy of a previous document describing a transfer of property to Wah from his brother. After the text was written, a later line was included mentioning that Wah's son had been born.[123]

The Rhind Mathematical Papyrus (P. BM 10057-58) is a mathematical text supposedly found in Thebes in a building near the Ramesseum, although this is not certain. It was then purchased in Luxor by A. Henry Rhind in 1858 CE.[124] The circumstance of purchase is not challenged in the literature.[125] The text, made by the scribe Ahmose in the fourth month of inundation of year 33 of the reign of Aauserre, a Hyksos king of the Fifteenth Dynasty of the Second Intermediate Period, is said to be a copy of a text written in the reign of Amenemhat III, a pharaoh of the Twelfth Dynasty of the Middle Kingdom. These dates are very well established in the literature.[126,127] Some have pointed out that, if the papyrus mentions a Hyksos king, it could very well be that it was created in Lower Egypt, the seat of Hyksos power, and then brought to Thebes later.[128] The text contains reference tables of numbers and calculations, as well as word problems that have been worked out.

Papyrus Ebers is a collection of medical knowledge dated to about 1500 BCE, in the reign of Amenhotep I, an early pharaoh of the Eighteenth Dynasty of the New Kingdom.[129] Historically, there has been some debate over the dating of the text, with some even proposing

[119] Parkinson, Richard B. *Voices from Ancient Egypt: an anthology of Middle Kingdom writings*. British Museum, 1991.
[120] Collier, Mark and Quirke, Stephen. *The UCL Lahun Papyri: Religious, Literary, Legal, Mathematical and Medical*. BAR International Series 1209. Oxford: Archaeopress, 2004.
[121] Parkinson, Richard B. *Voices from Ancient Egypt: an anthology of Middle Kingdom writings*. British Museum, 1991.
[122] Dr. Brian Muhs (Associate Professor of Egyptology, University of Chicago) in discussion with the author, March 2022.
[123] Parkinson, Richard B. *Voices from Ancient Egypt: an anthology of Middle Kingdom writings*. British Museum, 1991.
[124] Chace, Arnold B. *The Rhind Mathematical Papyrus*. Oberlin, OH: Mathematical Association of America, 1927.
[125] Robins, Gay, and Charles Shute. *The Rhind Mathematical Papyrus. An Ancient Egyptian Text*. London: British Museum Publications, 1987.
[126] Peet T. Eric. *The Rhind Mathematical Papyrus British Museum 10057 and 10058*. London: University Press of Liverpool, 1923.
[127] Spalinger, Anthony. "The Rhind mathematical Papyrus as a historical document." *Studien zur Altägyptischen Kultur* 17 (1990): 295-337.
[128] Spalinger, Anthony. "The Rhind mathematical Papyrus as a historical document." *Studien zur Altägyptischen Kultur* 17 (1990): 295-337.
[129] Bryan, Cyril P. *Ancient Egyptian Medicine: The Papyrus Ebers (Translated from the German Version)*. Chicago, IL: Ares Publishers, 1930.

that the text was written in the Ptolemaic period, but this has largely been resolved.[130] The papyrus includes a date and a cartouche, which aligns with the reign of Amenhotep I. This strong dating has been used as an anchor point for establishing ancient Egyptian chronologies, recently in tandem with ^{14}C dating. Edwin Smith purchased the text in Luxor in 1862 CE, but the original provenance is unknown, although it is likely from Thebes.[131] It has been proposed that the text could have been found in a Theban doctor's tomb.[132] Georg Ebers purchased the text in 1872 CE. The text is composed of a number of medical remedies, likely collected over time from various sources. The pages are numbered, an uncommon feature of ancient Egyptian papyri.[133] In addition, Erman pointed out some similarities in paleography between Papyrus Ebers, Papyrus Westcar, and the Rhind Papyrus.[134]

The "Texte aus Hatnub" are inscriptions by visitors on the walls of the Hatnub alabaster quarries near Tell el-Amarna.[135] There are many inscriptions at the Hatnub site ranging from the Old to the New Kingdom of Egypt, but the particular inscriptions used in this paper are from the Middle Kingdom.[136] These inscriptions were rediscovered in 1891 CE by Percy Newberry and Howard Carter and are dated to the fourth year of the nomarch Nḥri, who lived a bit before the beginning of the Twelfth Dynasty. For a deeper look at the dating of these Nḥri-inscriptions from various perspectives, a reader is encouraged to read Elke (1976).[137] The Hatnub texts are very different from traditional hieratic given that they were inscribed into rock rather than drawn on papyrus.[138] Thus, these texts serve as a good outgroup for the data set. Anthes makes note that, paleographically, the Middle Kingdom Hatnub graffiti shares remarkable similarities to P. Berlin 10482.[139] This is interesting, because P. Berlin 10482 contains a number of lines from the Coffin Texts, is from Asyut, and is on papyrus: a different content, provenance, and medium than the Hatnub texts.[140] Nevertheless, the time period could line up with the Hatnub texts, so one cannot rule out common authorship.

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[130] Kromer, Bernd, Lutz Popko, and Reinhold Schell. "Die Altersbestimmung des Papyrus Ebers." *Göttinger Miszellen: Beiträge zur ägyptologischen Diskussion* 257 (2019): 63-72.
[131] Ebers, Georg, and Ludwig Stern. *Papyros Ebers: Das Hermetische Buch über Die Arzeneimittel Der Alten Ägypter in Hieratischer Schrift*. Leipzig: Engelmann, 1875.
[132] David, Rosalie. "The ancient Egyptian medical system." Essay. In *Egyptian Mummies and Modern Science*, edited by Rosalie David, 181-94. Cambridge: Cambridge University Press, 2008.
[133] Cerný, Jaroslav. *Paper and Books in Ancient Egypt. An inaugural lecture delivered at University College London, 29 May 1947*. Ares Publ., 1952.
[134] Erman, Adolf. *Die Märchen Des Papyrus Westcar: I: Einleitung Und Kommentar. II: Glossar, Palaeographische Bemerkungen Und Feststellung Des Textes*. Berlin: Spemann, 1890.
[135] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1
[136] Shaw, Ian. "Hatnub." Essay. In *Encyclopedia of the Archaeology of Ancient Egypt*, edited by Kathryn A. Bard and Steven Blake Shubert, 363–65. London: Routledge, 1999.
[137] Blumenthal, Elke. "Die Datierung der Nhri-Graffiti von Hatnub." *Altorientalische Forschunge*n 4, no. JG (1976): 35-62.
[138] Enmarch, Roland, and Yannis, Gourdon. "Quarry Epigraphy at Hatnub", in C. Ragazzoli and K. Hassan (eds), *Graffiti, Secondary Epigraphy and Rock Inscriptions from Ancient Egypt* (Cairo, Institut français d'archéologie orientale). (2020).
[139] Anthes, Rudolf. "Die Felseninschriften von Hatnub nach den Aufnahmen Georg Möllers." *Untersuchungen zur Geschichte und Altertumskunde Ägyptens* 9 (1928).
[140] Regulski, Ilona. *Repurposing Ritual: Pap. Berlin p. 10480-82: A Case Study from Middle Kingdom Asyut*. Berlin: Walter de Gruyter GmbH, 2020.

Table 2: Information on each of the original texts whose facsimiles were used for this project

Text	Papyrus	Facsimile Maker	Genre	Date	Origin	Signs in Data Set
Shipwrecked Sailor	P. Hermitage 1115	Poe/ Tabin	Literary	Twelfth Dynasty?	Unknown (Thebes?)	3061 (Tabin)/ 511 (Poe)
Eloquent Peasant B1	P. Berlin 3023	Möller/ Tabin	Literary	Twelfth Dynasty	Thebes	1218 (Möller)/ 1793 (Tabin)
Eloquent Peasant R	P. Ramesseum A	Möller	Literary	Thirteenth Dynasty	Thebes	137
The Story of Sinuhe B	P. Berlin 3022	Möller	Literary	Twelfth Dynasty	Thebes	1581
The Story of Sinuhe R	P. Ramesseum A	Möller	Literary	Thirteenth Dynasty	Thebes	391
The Maxims of Ptahhotep	P. Prisse	Möller	Instruction	Twelfth Dynasty	Thebes (likely)	444
Lahun Temple Files	P. Berlin 10003	Möller	Administrative	Twelfth Dynasty	Lahun	174
The Will of Wah	UC 32058	Möller	Administrative	Twelfth Dynasty	Lahun	564
Hymn to Senwosret III	UC 32157	Möller	Hymn	Twelfth Dynasty	Lahun	959
Texte aus Hatnub	NA	Möller	Inscription	Twelfth Dynasty	Hatnub	246
Papyrus Westcar	P. Berlin 3033	Möller	Literary	Eighteenth Dynasty? (Original composition from Twelfth Dynasty)	Unknown	607
Papyrus Ebers	P. Ebers	Möller	Medical	Eighteenth Dynasty	Unknown (Thebes?)	1022

Rhind Mathematical Papyrus	P. BM 10057-58	Möller	Mathematical	Fifteenth Dynasty (Copy of text from Twelfth Dynasty)	Unknown (Thebes?)	440

Sources for the Data Set

The data set used for this project consists of individually cut out hieratic characters from facsimiles made by myself (henceforth referred to as "Tabin's facsimile"), Georg Möller in his "Hieratische Lesestücke",[141] and William Poe in his "Introduction to Hieratic Middle Egyptian".[142] My facsimiles and Poe's were already digital, whereas Möller's had to be digitized through high quality scans. All of the facsimiles were color-corrected to be purely black and white.

I created two facsimiles by hand, one of the full story of The Shipwrecked Sailor and one of the beginning of The Eloquent Peasant. These texts were selected for three reasons. First, they are both lengthy, with many individual signs, resulting in a multitude of data points each. Second, they both have lots of published information about them, including clear images. Third, they both have versions done by other facsimile makers: Poe created a full Shipwrecked Sailor facsimile and Möller created a partial Peasant facsimile. These factors allow for easier creation and many potential comparisons. My facsimiles were created, using methods discussed below, to be as morphologically accurate to the original texts as possible. They were created in Photoshop using images of the original papyrus digitized from Golénischeff's Shipwrecked Sailor publication and Parkinson and Baylis's Eloquent Peasant publication respectively.[143, 144]

In contrast to my facsimiles, Poe's Shipwrecked Sailor facsimile is less focused on being morphologically accurate, opting instead to be a simplified teaching tool for Middle Egyptian hieratic. The individual signs are far more block-like and smooth, without the sharper points that appear in hieratic made from physical brush strokes. Poe produced his facsimile by scanning Golénischeff's Shipwrecked Sailor images and then tracing them on a computer in CorelDRAW™, a digital image editing software.[145] Thus, Poe's facsimile still maintains the basic shape of each character, but disregards the minutiae of each sign's detail. This is useful in multiple ways. For example, if a sign from Poe's facsimile is put into the program, the program should output what signs are most similar to that one. If the signs that are most similar are all from his facsimile, even if a different version of that exact sign is in the data set from a different facsimile maker, that is a good indication that the general shape is not enough to determine a specific sign. If the reverse is true and the same sign from Poe's facsimile and Tabin's facsimile are shown to be most similar, then it indicates that larger shapes of signs are most important. In this vein, Poe's facsimile can be used to investigate questions relating to modern facsimiles and how accurate they need to be to capture the true variation of hieratic. It is also a good addition to

[141] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch.* Leipzig: Hinrichs, 1909. Vol. 1

[142] Poe, William Clay. *The Writing of a Skillful Scribe: An Introduction to Hieratic Middle Egyptian Through the Text of the Shipwrecked Sailor.* Sonoma State University, 2008.

[143] Golénischeff, W. *Les Papyrus Hieratiques No 1115, 1116A et 1116B de l'Ermitage Imperial a St Petersbourg*. St Petersburg: Ermitage Imperial, 1913.

[144] Parkinson, Richard B. and Baylis, Lisa. *Four 12th Dynasty Literary Papyri* (Pap. Berlin P. 3022-5): A Photographic Record. Berlin: Akademie Verlag, 2012.

[145] Poe, William Clay. *The Writing of a Skillful Scribe: An Introduction to Hieratic Middle Egyptian Through the Text of the Shipwrecked Sailor.* Sonoma State University, 2008.

the data set in a practical sense because someone using the program on their own facsimile might not have produced that facsimile with in-depth morphological accuracy in mind; the more variation present in the data set, the better it will be at recognizing foreign inputs. Due to time constraints, only the first four pages of Poe's facsimile were added to the data set. These pages overlap in content with my own Shipwrecked Sailor facsimile.

Möller, who cataloged hieratic morphological variation over 100 years ago, produced a number of high-quality facsimiles spanning a wide range of genres, locations, and time periods. For this project, only his facsimiles from "Hieratische Lesestücke für den akademischen Gebrauch Vol. 1" were used because they are all written in Middle Egyptian and can all be dated to around the Middle Kingdom.[146] Möller produced his facsimiles by drawing them on photographs or gelatin drawings, while constantly comparing the facsimiles to the originals. This process produced facsimiles that are fairly morphologically accurate, especially since Möller marked all of the damaged areas. I used almost all of his facsimiles, although a few were left out due to time constraints. Most of his facsimiles are only excerpts from each text, rather than the whole of each. The Möller facsimiles used were those of the Hatnub texts, Lahun temple files, Will of Wah, Hymn to Senwosret, Eloquent Peasant, Papyrus Prisse, Sinuhe, Papyrus Ebers, the Rhind Mathematical Papyrus, and Papyrus Westcar. Of these, his Eloquent Peasant facsimile overlaps with mine to a certain extent.

[146] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1

Methods

In this section, all of the analysis methods used for this work, technical, conceptual, and statistical, will be discussed. For ease of readability, a list of subsections is produced below:

1. Facsimile Creation
2. Facsimile Annotations
3. Sign Separation Program
4. Glyph Labeling
5. Data Set Preparation
6. The Comparison (OCR) Program
   a. Calculation of data set metrics
   b. Filtering by aspect ratio
   c. Filtering by Fast Fourier Transform
   d. Image Distortion Model
   e. Other comparative methods
   f. Sign identification
7. Data Analysis

Facsimile Creation

My two facsimiles of the Shipwrecked Sailor and part of the Eloquent Peasant were both created in a similar fashion in Adobe Photoshop (Versions 22-23.1) on a MacBook Pro laptop (16-inch, 2019). The first step was obtaining clear images of the original papyri. For the Shipwrecked Sailor, the images came from Golénischeff's publication of the text.[147] For the Eloquent Peasant, the images came from Parkinson and Baylis's publication.[148] Once the images were loaded into Photoshop, they were traced using a Wacom Intuos Pro (Paper Edition) tablet connected to the computer.

To trace the images, a new Photoshop layer was created above the original image. This new empty layer was set to 50% opacity. Then, the Pencil tool was used to trace the signs around their edges. The 50% opacity allowed for high accuracy, because the tracings were see-through and I was able to see how well the signs' edges lined up to the drawing as they were being traced. The Pencil tool was chosen because it produces a solid color when drawing, rather than a fading boundary. The pencil's color was set to black (R: 0, G: 0, B: 0) and the brush diameter was set to 2 px for the Shipwrecked facsimile and 1 px for the Peasant facsimile. This difference was due to the size of the original images. The sixteen Shipwrecked images were 10400 px × 5592 px (resolution: 300 ppi) each, whereas the five peasant images were 5199 px × 3902 px (resolution: 300 ppi) each. Thus, the bigger Shipwrecked images necessitated a larger pencil size. Although the Shipwrecked images were larger, they were also less clear, likely due to the early

[147] Golénischeff, W. *Les Papyrus Hieratiques No 1115, 1116A et 1116B de l'Ermitage Imperial a St Petersbourg*. St Petersburg: Ermitage Imperial, 1913.
[148] Parkinson, Richard B. and Baylis, Lisa. *Four 12th Dynasty Literary Papyri (Pap. Berlin P. 3022-5): A Photographic Record*. Berlin: Akademie Verlag, 2012.

era when the images were taken. However, this did not meaningfully inhibit the creation of the facsimile.

In tracing the signs, obvious damage was repaired, as is common for most facsimiles. For instance, if a sign had a hole in the middle where the papyrus was clearly ripped, but the rest of the sign was known, the hole would be ignored in the tracing. As for signs with heavier damage, where significant extrapolation would be needed to restore the sign, the signs were still restored to the best of my ability for the Shipwrecked facsimile, but often not for the Peasant facsimile. This is purely due to time constraints. The restorations were done by referencing published transcriptions of the texts,[149,150,151] common sign forms,[152] and by copying non-damaged examples of the damaged signs from the same text. Then, an outline of what the sign would be expected to look like was created.

After all of the signs were traced, the work was checked to make sure there were no issues. Then, the Paint Bucket tool was used to fill in each of the outlined signs with black pixels. The tool was set to have the default tolerance of 32, the contiguous setting was turned on, and anti-aliasing was turned off. This resulted in each sign being filled in up to, but not beyond, the borders drawn during the tracing step. Anti-aliasing was especially important to be turned off, because otherwise the paint bucket would fill in pixels beyond the borders, widening each sign and tampering with the morphological accuracy. The signs were all filled in one by one to ensure that it was done accurately and then the final product was once again checked.

Throughout the process, there were many points where it had to be decided what was a real sign versus what was a smudge, damage to the papyrus, or an accidental ink spot. To do this, I consulted a number of sources: Hieratische Paläographie for sign forms,[153] JSesh for a digital sign list,[154] Thesaurus Linguae Aegyptiae for usual spellings of words,[155] and publications of the texts for accepted transcriptions.[156,157,158] Despite all of this, it must be acknowledged that the facsimiles are not perfect. There are probably some points in each facsimile where I neglected to restore some damage or did not trace a sign completely right. However, I tried to make the facsimiles as morphologically accurate as possible, even if they deviated from the "ideal" or anticipated shape. This sometimes resulted in characters that are perhaps too accurate (i.e. they have many little ink outcroppings that may not have been necessarily intended by the scribe).

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[149] Casey, Christian. *The Story of the Shipwrecked Sailor: Transcription, Transliteration, and English Translation with Full Commentary*. University of Texas at Austin, 2008.
[150] Parkinson, Richard B. *The Tale of the Eloquent Peasant*. Griffith Institute, Ashmolean Museum, Oxford, 1991.
[151] Nederhof, Mark-Jan. *St Andrews Corpus*. https://mjn.host.cs.st-andrews.ac.uk/egyptian/texts/corpus/pdf.
[152] Nagai, Masakatsu, Waki, Toshihito, Takahashi, Yona, and Nakamura, Satoru. *Hieratische Paläographie DB*. Tsukuba University. January 31, 2021. https://moeller.jinsha.tsukuba.ac.jp.
[153] Nagai, Masakatsu, Waki, Toshihito, Takahashi, Yona, and Nakamura, Satoru. *Hieratische Paläographie DB*. Tsukuba University. January 31, 2021. https://moeller.jinsha.tsukuba.ac.jp.
[154] Rosmorduc, Serge. *JSesh Documentation*. June 12, 2014. http://jseshdoc.qenherkhopeshef.org.
[155] Thesaurus Linguae Aegyptiae. *BBAW, Ancient Egyptian Dictionary Project*. November 10, 2021. https://aaew.bbaw.de/tla/servlet/TlaLogin.
[156] Casey, Christian. *The Story of the Shipwrecked Sailor: Transcription, Transliteration, and English Translation with Full Commentary*. University of Texas at Austin, 2008.
[157] Parkinson, Richard B. *The Tale of the Eloquent Peasant*. Griffith Institute, Ashmolean Museum, Oxford, 1991.
[158] Nederhof, Mark-Jan. *St Andrews Corpus*. https://mjn.host.cs.st-andrews.ac.uk/egyptian/texts/corpus/pdf.

The philosophy when making these facsimiles was that erroneously not including a small ink stroke could completely change the sign's meaning, whereas including a small ink stroke that was not intended would still preserve the core shape of the sign. This largely holds up, although there are individual examples where the reverse is true.

Given that it would be lengthy to describe every single instance where a decision was made about damage (whether or not to trace it, fill it in, ignore it, etc.), a third layer was added on top of the facsimile and original text layers. This layer, called the "damage" layer, was also traced and then filled in according to the methods outlined above. However, this time, I traced the outlines of places which I considered damaged. In addition, red (R: 255, G: 0, B: 0) was used for the Pencil tool, rather than black. A reader interested in the decisions regarding damage made during the facsimile creation process is encouraged to look at the copies of my facsimiles with the damage layer shown (see Appendix 2). Due to time constraints, a damage layer was not created for all pages of the Peasant facsimile, but this is less important, given that few significant extrapolations were made.

To complete the facsimiles, a fourth layer was created for numbers. In this layer, the Horizontal Type tool was used to label each of the lines of the text with their accepted line number. Each text's line numbers were taken from the publications of the original images.[159,160] The text was typed in Times New Roman font and colored black. After all of the layers were finished, the facsimile layer was changed to 100% opacity and the original image was hidden. In this form, the Photoshop file was exported as a .png file, resulting in just the facsimile, damage (50% opacity), and the numbers on a white background. A version of the file was also exported with the damage layer hidden, resulting in a "clean" .png file with just the facsimile and the numbers. As I created the facsimiles, my skill with the methods and tools improved, as well as my familiarity with the texts. Due to this, the Shipwrecked facsimile was completely redone after it was completed for the first time, due to potential improvements. The first version of the Shipwrecked facsimile was far less morphologically accurate and also contained many errors. Nevertheless, it was saved as a potential comparison tool to be used in future work.

Facsimile Annotations

In order for individual characters from each facsimile to be separated into their own separate images by Sobti (discussed below), the facsimiles had to be manually annotated. Because of the difficulty of separating hieratic characters and the lack of an existing hieratic data set, it was necessary to do this by hand. Ideally, the results of this project and future work could be used to automate this process in the future.

To begin the annotations for a given facsimile page, an image of the page was loaded into Photoshop. The image was then color corrected to be made up of purely black or white pixels. This was not needed for the Tabin facsimiles, as they were already like this. The Möller

[159] Golénischeff, W. *Les Papyrus Hieratiques No 1115, 1116A et 1116B de l'Ermitage Imperial a St Petersbourg*. St Petersburg: Ermitage Imperial, 1913.
[160] Parkinson, Richard B. and Baylis, Lisa. *Four 12th Dynasty Literary Papyri (Pap. Berlin P. 3022-5): A Photographic Record*. Berlin: Akademie Verlag, 2012.

facsimiles were scans, so they were closer to gray writing on beige paper than black and white,[161] and the Poe facsimiles were mostly black or white, but with stray pixels within each sign that had to be corrected.[162] This color correction was done using Photoshop's Magic Wand tool with a tolerance of 60, the contiguous setting turned off, and anti-aliasing turned off. These settings were chosen based on trial and error for what worked best with the specific facsimile images. The Magic Wand tool was used to select all of the signs that were supposed to be purely black (R: 0, G: 0, B: 0) and then the Fill setting in the Edit menu was used to fill them in. Likewise, the background, which was supposed to be purely white, was filled in with white (R: 255, G: 255, B: 255) in the same manner. This process was not trivial due to the prevalence of color gradients, especially in Möller's facsimiles; sometimes the exact border between a sign and the page was not clear or lighter pixels than expected appeared within signs, not being selected by the Magic Wand tool on the first pass. However, through thorough revisions and multiple uses of the Magic Wand tool, all of the facsimiles ended up being accurately color corrected.

After the facsimiles were purely composed of black and white pixels, they had to be annotated. They were annotated in five layers of 50% opacity: Red, Green, Blue, Even, and Odd. The first three of these layers were made up of colored shapes that surrounded each individual sign. The shapes were drawn with the Pen tool using the Shape setting, a solid Fill color, no Stroke fill color, solid lines, and Combine Shapes selected. The Pen tool was used to create anchor points, making a polygon around the signs. Thus, each individual sign in its entirety was encased in a colored polygon. Each layer's shapes were filled in with a different color: red (R: 255, G: 0, B: 0), green (R: 0, G: 255, B: 0), and blue (R: 0, G: 0, B: 255), respectively. Three layers of different colors were used so that two separate signs that are near one another were not mistaken for the same sign by the program. For example, if one color was used, two signs physically close together, which do not touch one another, could have their surrounding polygons touch or nearly touch one another. Then, the two shapes would look like one to the program and the signs would not be cut out correctly. To make sure each sign was only annotated in one of the three color layers and that there would be no issues of colors being too close, the Red layer was created first and every third sign was put in a red polygon. Then, the same was done for the Green layer and then the Blue layer, each only encapsulating signs that were not previously annotated in a prior layer.

To effectively annotate the document, criteria were created for what was to be taken as an "individual sign". Because hieratic often contains ligatured and overlapping characters, it is impossible to say for certain where one character ends and another begins at times. If this was the case, the signs were taken as one. This method sometimes resulted in "one" character being composed up to five or more signs, effectively decreasing the size of the data set, but this is a necessary limitation of the methods. If one were to artificially separate two signs when they overlap by drawing polygons between the signs, one would be making a human judgment call and introducing modern biases into the data. It is also worth noting that some signs change their

[161] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1
[162] Poe, William Clay. *The Writing of a Skillful Scribe: An Introduction to Hieratic Middle Egyptian Through the Text of the Shipwrecked Sailor*. Sonoma State University, 2008.

common forms only when in specific ligatures, so ignoring the ligature element and separating the signs would be losing valuable information.[163,164] In some cases, signs overlapped, but where each sign began and ended was still clear. In these cases, the signs were separated. The only times signs were left unseparated was if it could not be determined where one ended and the other began. Of course, even this comes down to a judgment call and there are likely some biases introduced into the data set because of this. Nevertheless, the goal was to minimize bias, while maximizing the size, breadth, and accuracy of the data set and the methods were chosen for this purpose.

Once every sign was encased in a colored polygon, the Odd and Even layers were created. These layers were constructed using the same method as the color layers, but, instead of surrounding individual signs, they surrounded each line of text. The Odd layer, filled in with yellow (R: 255, G: 255, B: 0), surrounded the odd numbered lines. The Even layer, filled in with magenta (R: 255, G: 0, B: 255), surrounded the even numbered lines. The same rationale was used for why the color layers were different colors, preventing the program from mistaking two close lines for being the same line. After all of the layers were made, the work was saved as a Photoshop Document (.psd) file. An example of the annotations described here is given in Figure 1.

Sign Separation Program

To separate each individual sign from the annotated facsimiles, I worked with Dr. Christian Casey at the Institute for the Study of the Ancient World (ISAW) to develop a program to do so, which he largely coded and named Sobti (ϹⲞⲂϮ). Sobti is a web-app coded in Python through the high-level web framework of Django. The original design was to have the program cut out the hieratic signs, as well as label them. Unfortunately, Sobti was not able to be fully operational within the timeframe of this project, but, luckily, the part of the program that cut out the characters was able to be finished.

To use Sobti, an annotated .psd file prepared according to the specifications outlined above is uploaded as its input. The program saves a copy of the .psd, along with a .png of the page with all its layers and a .png of the page alone. Then, the individual signs annotated in the three color layers in the Photoshop file are recorded, as well as which line they are in. This line information is gained from the Even and Odd layers. Each identified layer and line is saved in a folder as a .png file. Then, each individual sign is saved in a folder as a .png with their file names indicating their line number and position. For example, a glyph saved as "003_0016.png" is the 16th character in the 3rd line of the page. This method is not always perfect, however. Sometimes individual, non-contiguous pixels will be counted by the program as extra lines or extra signs. This can be manually corrected after the fact by simply deleting erroneous characters and lines, but it does alter the line and sign numbers in the filenames. In addition, a human's intuition about which signs come before others in a text has little power over Sobti's distinctions.

[163] Nagai, Masakatsu, Waki, Toshihito, Takahashi, Yona, and Nakamura, Satoru. *Hieratische Paläographie DB*. Tsukuba University. January 31, 2021. https://moeller.jinsha.tsukuba.ac.jp.

[164] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1

Although Sobti is coded to have similar decisions as a human might (i.e. signs to the right come first in a line), it is not always correct because the program does not always take the top character in a group as the first one. For instance, a group could consist of Gardiner signs N35:A1 (*n=i*) on top of one another and, although a scholar would read the N35 sign first, the program might read the A1 sign first due to its location being slightly more to the right, despite being below. This is uncommon and does not affect any of the analysis for this project, but it is worth mentioning in case others use the program.

The glyphs that are saved as .png files are cut out of the text within their respective polygons from the annotations. Each image consists of a black glyph with a white background to the extent that both are captured by their polygon. Thus, the final result of using Sobti is a folder containing individual images of all of the glyphs that have been cut out, labeled with their line and position within the line. The images in this folder, as well as the other folders of lines and layers, are called on by Sobti when displaying the text. If one removes these glyphs, the display will not work, so one must delete a text from the program after removing the glyphs from the folder. This is not an issue because one can always reupload a text and have the images produced anew. Sobti also has issues with facsimile pages with too many signs (greater than about 250) and it will stop identifying signs past that point. This is purely a technical issue and it can be circumvented by cropping a facsimile page and uploading two half-sized pages rather than one whole one.

In the future, Sobti needs improvements. Although it works well to separate images from the annotated Photoshop documents, there are many ways it could be made better. The main feature that should be added is the labeling element. Sobti has a designed interface for the labeling, but it is not efficient at the moment and could be adjusted. In addition, minor bugs, such as the glyph limit per page, the stray pixels being counted as signs, and the misordering of signs in a group, could all be worked out with more time. Once these are worked out, Sobti, being already implemented in Django, would be usable as a web app. Beyond these goals, eventually the use of OCR should be able to make the annotation of the .psd files automatic, allowing a user to only have to correct the annotations, rather than create them from scratch. This would allow high-speed analysis and digitization of hieratic texts and make them usable in the data set in seconds. This is not possible at the moment, but it is hopefully not too far off.

Glyph Labeling

After the individual glyphs were extracted by Sobti, they were put into folders whose names convey their text of origin, its provenance, and its facsimile creator. For instance, signs from the Tabin copy of the Eloquent Peasant were put in a folder titled "Peasant" which was within a folder titled "Thebes" which was within a folder titled "Tabin". The base folders with the glyphs were then used as an input for a renaming program written in Python using Jupyter Notebook. The renaming program takes the folder, produces a list of all of the names of the files in it, and prompts a user to input each image's Gardiner sign.[165] Then, the program renames the respective file with the inputted sign code and how many times it has appeared in the text in the following format: [Sign Code]_XXXX.png. As a concrete example, the third A1 sign to appear in a text would be labeled "A1_0003.png". This renaming overwrites the previous information from Sobti about line number and location within lines, but, due to the imperfections in Sobti's method, this is not a substantial loss. The result of the program is that all of the images in the folder are labeled with their Gardiner sign codes.

Some signs, which are clearly different in their hieroglyphic forms, are not different in their hieratic forms. This led Möller to consider many of them as one sign form.[166] I have followed Möller's lead. For example, signs U6 () and U7 () are both hoe signs and are distinct in hieroglyphic form: U6 is tilted upwards whereas U7 is horizontal.[167] However, in hieratic, this distinction is never made. Therefore, all of the signs of that form could be U6, they all could be U7, or there could be a mix, but the signs are indistinguishable and this cannot be known. Because of this, I have taken every sign that could be U6 or U7 as U7. This was done for many signs where this problem occurs, given that there is no known way to tell the difference and it would be introducing personal bias to make the distinctions myself. Some more examples of signs dealt with in this way are: A40/A41 (/) was taken as A40, G40/G41 (/) was taken as G41, N11/N12 (/) was taken as N11, T9/T9A (/) was taken as T9, U28/U29 (/) was taken as U29, W17/W18 (/) was taken at W17, Z9/Z10 (/) was taken as Z9, and Aa15/Aa16 (/) was taken as Aa15. If a sign does not appear in the data set, there could be no examples of it in the texts used, but it could also be wrapped up under the umbrella of another sign that was impossible to distinguish from it.

The last quirk of the labeling method to note is that there was no Gardiner sign present for the beginning of a cartouche.[168] Traditionally, sign code V10 is used for the whole cartouche and V11 is used for just the end. Since cartouches in hieratic are often written split up, sign code V10 was here used for cartouche beginnings, rather than the whole cartouche.

This overall labeling method requires prior knowledge of what each sign is. This was determined manually, supplemented with the Hieratische Paläographie,[169] the Thesaurus Linguae Aegyptiae,[170] the JSesh texts list,[171] the Nederhof St. Andrews Corpus of Egyptian text

[165] Gardiner, Alan H. *Egyptian Grammar: Being an Introduction to the Study of Hieroglyphs.* 3. ed., Oxford: Griffith Institution, 1957.
[166] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1
[167] Hieroglyphic unicode keyboard provided by Dr. Christian Casey from https://www.caseyegyptologist.com/downloads.
[168] Gardiner, Alan H. *Egyptian Grammar: Being an Introduction to the Study of Hieroglyphs.* 3. ed., Oxford: Griffith Institution, 1957.
[169] Nagai, Masakatsu, Waki, Toshihito, Takahashi, Yona, and Nakamura, Satoru. *Hieratische Paläographie DB*. Tsukuba University. January 31, 2021. https://moeller.jinsha.tsukuba.ac.jp.
[170] Thesaurus Linguae Aegyptiae. *BBAW, Ancient Egyptian Dictionary Project*. November 10, 2021. https://aaew.bbaw.de/tla/servlet/TlaLogin.
[171] Rosmorduc, Serge. *JSesh Documentation*. June 12, 2014. http://jseshdoc.qenherkhopeshef.org.

transliterations,[172] and the Stableford Corpus of transliterations of Möller's work on hieratic.[173] The signs were then checked against published transliterations of the texts: the Collier and Quirke publication of the Lahun papyri,[174] the Parkinson publication of the Eloquent Peasant,[175] the Koch publication of the Story of Sinuhe,[176] the Žába and Gustave publications of Papyrus Prisse,[177,178] the Golénischeff and Casey publications of the Shipwrecked Sailor,[179,180], the Wreszinski publication of Papyrus Ebers,[181] the Erman and Blackman publications of Papyrus Westcar,[182183] and the Chace publication of the Rhind papyrus.[184] In the future, this program could be improved with OCR. Adding an OCR program would identify most of the characters with high accuracy, preventing a user from having to manually input each sign code. Instead, a user would only have to correct any errors. This function could even be wrapped up in Sobti, fusing the two programs. A similar method was used by Nederhof in his work on identifying Sethe's glyphs through OCR; as more images were added to the data set, OCR was able to be relied on for identifications more and more.[185]

Data Set Preparation

Before the data set could be used for OCR, the images had to undergo pre-processing. The first step was to use a program written in Python to combine folders from the same text and "tag" the signs with their folder information. Prior to this, the individual images were in folders corresponding to their facsimile pages (ex. "Peasant B1 32-41", "Peasant B1 42-50", etc.). The program first combined all the folders from a single text into one, adjusting image names as it went. For example, if there were 25 A1 signs from the first page of a facsimile and, thus, the last A1 image was labeled A1_0025.png, the first A1 from the second page would be relabeled to A1_0026.png when moved to the new folder. Then, the program would further adjust the image

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[172] Nederhof, Mark-Jan. *St Andrews Corpus*. https://mjn.host.cs.st-andrews.ac.uk/egyptian/texts/corpus/pdf.
[173] Stableford, Tom. *Translation of Georg Möller's works on Hieratic*. http://www.egyptologyforum.org/bbs/Stableford/StablefordMoeller.html
[174] Collier, Mark and Quirke, Stephen. *The UCL Lahun Papyri: Religious, Literary, Legal, Mathematical and Medical*. BAR International Series 1209. Oxford: Archaeopress, 2004.
[175] Parkinson, Richard B. *The Tale of the Eloquent Peasant*. Griffith Institute, Ashmolean Museum, Oxford, 1991.
[176] Koch, Roland. *Die Erzählung des Sinuhe*. Fondation Égyptologique Reine Élisabeth, Brussels, 1990.
[177] Zbyněk Žába. *Les maximes de Ptaḥḥotep*. Prague: Éditions de l'Académie Tchécoslovaque des Sciences, 1956.
[178] Jéquier Gustave. *Le Papyrus Prisse Et Ses Variantes: Papyrus De La Bibliothèque Nationale (Nos 183 à 194), Papyrus 10371 ET 10435 Du British Museum, Tablette Carnarvon Au Musée Du Caire: Publiés En Fac-similé (16 Planches En Phototypie)*. Paris: Librairie Paul Geuthner, 1911.
[179] Golénischeff, W. *Les Papyrus Hieratiques No 1115, 1116A et 1116B de l'Ermitage Imperial a St Petersbourg*. St Petersburg: Ermitage Imperial, 1913.
[180] Casey, Christian. *The Story of the Shipwrecked Sailor: Transcription, Transliteration, and English Translation with Full Commentary*. University of Texas at Austin, 2008.
[181] Wreszinski, Walter, ed. *Der Papyrus Ebers; Umschrift, Übersetzung und Kommentar.* Vol. 1. Hinrichs, 1913.
[182] Erman, Adolf. *Die Märchen Des Papyrus Westcar: I: Einleitung Und Kommentar. II: Glossar, Palaeographische Bemerkungen Und Feststellung Des Textes*. Berlin: Spemann, 1890.
[183] Blackman, Aylward M. *The story of King Kheops and the magicians: transcribed from Papyrus Westcar (Berlin Papyrus 3033)*. JV Books, 1988.
[184] Chace, Arnold B. *The Rhind Mathematical Papyrus*. Oberlin, OH: Mathematical Association of America, 1927.
[185] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond, Leipzig (2015).

names by prompting a user to add "tags" for each folder. These tags are numbers put at the end of the file names, corresponding to the facsimile maker, provenance of the text, and the text itself, in that order. These tags are given in Table 3. For an example of how these tags work, the 21st A1 from Möller's facsimile of the Will of Wah would be named "A1_0021_1_2_9.png". This system of labeling was chosen so the data for each sign could be readily accessible when the glyph was being used in comparisons.

Table 3: The tags used for the data set images

Number	Facsimile Maker	Provenance	Text
1	Möller	Thebes	Shipwrecked Sailor
2	Poe	Lahun	Eloquent Peasant B1
3	Tabin	Hatnub	Eloquent Peasant R
4		Unknown	Sinuhe B
5			Sinuhe R
6			Papyrus Prisse
7			Hymn to Senwosret III
8			Lahun Temple Files
9			Will of Wah
10			Texte aus Hatnub
11			Papyrus Ebers
12			Rhind Papyrus
13			Papyrus Westcar

After the files were labeled, the actual images had to be standardized, rather than left as irregular polygons. To do this, a Python program was written using the Python Imaging Library (PIL) package. The PIL adds the ability to process images in Python. When a folder is inputted, the program loads in each image individually. Then, the northernmost, easternmost, westernmost, and southernmost black pixels are located and the image is cropped on all sides to those pixels. By cropping to the very edges of each sign, the program prevents human error in variable polygon sizes carrying over from the annotation step. After cropping the image, all pixels that are not black are colored white, including transparent pixels. Thus, the shape of the image as a whole becomes a rectangle, with all pixels in its bounds being either black or white. This correction is important for the comparisons in the OCR program, because all images need to be compared from the same starting position: black and white pixels with a rectangular shape.

The Comparison (OCR) Program

The purpose of the OCR program is to identify input hieratic characters based on their morphology, ranking the data set characters based on similarity. Although the goal is simple, this is by no means a trivial task. Throughout the creation of the OCR program, written in Python, a balance had to be struck between accuracy and speed. One could make an extremely accurate program that compares an input sign to the entire data set, but that would take far too long to be feasible as a research tool. Conversely, a program that randomly ranks the signs in the data set would be extremely fast at doing so, but would be immensely inaccurate and profoundly unhelpful. Thus, in many areas of this project, tradeoffs had to be made. However, in some cases speed could be improved without sacrificing accuracy.

Calculation of data set metrics: Before any input glyphs are added to the program, the program calculates some metrics for the entire data set and saves it as a file. This only needs to happen once, because the metrics from the unchanging data set can then be called by the program rather than being calculated each time it is run.[186] To do this, a list of all of the images in the data set is loaded into the program. Using PIL, each image is loaded in and its aspect ratio is calculated by dividing its height in pixels by its width in pixels. The calculated aspect ratios are saved in a dataframe along with the image filenames and the sign codes extracted from those filenames. This dataframe is then saved as a .csv file in a newly created folder that can be easily accessed by the program.

After this, the images are all resized to be squares of a certain size. The images need to be resized so they can be compared to one another easily; it would be difficult to compare images with wildly different aspect ratios and resolutions. Each image will be distorted to some degree, but signs that looked similar before distortion should look similar after distortion, since they are all undergoing similar transformations. The resizing size is determined by a user, but, through extensive trials, 20 px by 20 px seems to be the best size to optimize speed without meaningfully sacrificing accuracy. Larger images will potentially be more accurate, although this is not always the case, but larger images will also take longer to run. The downside of resizing is that, to try and maintain image accuracy, the image will naturally gain gray pixels that are between white and black. This is fixed by the program which considers pixels that are closer to black (less than 127.5 for their color values) to be black (0 for the color values) and pixels that are closer to white

[186] Of course, this would need to be redone every time new material is added to the data set.

(greater than 127.5 for their color values) to be white (255 for the color values). Again, this should not affect the comparisons since every sign undergoes identical treatment. Once every image is resized, a list of its pixels is saved as a vector and added to a dataframe, next to a column of the sign names of each image. For example, an image that is 2 px by 2 px (much smaller than the ones used in this program) that has a black top-left pixel, a white top-right pixel, a white bottom-left pixel, and a black bottom-right pixel, would have a vector of [0, 255, 255, 0] (i.e. [black, white, white, black]). This method can be extended to images of any size. Finally, the dataframe of pixel values for every resized image from the data set is saved as a .csv file in the same folder as the aspect ratio list.

Filtering by aspect ratio: Once the data set metrics are all saved, a user can load in a new image that they want to identify. A user can also put in a whole folder of images to be identified, making large-scale comparisons easy to do. When a new sign is added to the program, it undergoes pre-processing in the same way that every image in the data set has: it is converted to purely black and white pixels (although ideally this would also be manually done beforehand to ensure accuracy), cropped to contain just the sign itself by locating its most distant black pixel on each side, has its transparent pixels filled in with white to make a rectangle, has its aspect ratio calculated and saved, is resized, and has its pixel values saved. All of this is done according to the above methods. Then, the aspect ratio of the input sign is compared to the aspect ratios of every sign in the data set and only the data set signs with aspect ratios close to that of the input sign are saved. Despite this sounding like a lot of calculation, this step is nearly instantaneous. The threshold for when two aspect ratios are "close" to one another is up to the user to input. However, through rigorous testing, a cutoff of 0.15 seems to be optimal. If two aspect ratios are within 0.15 of one another, they are considered "close" and the data set sign is saved. For the average input sign, this filtering step leaves about 1000-3000 candidate signs out of the 13,134 data set signs. Sometimes this number is a bit higher or far lower, depending on how common a sign's aspect ratio is. The candidate signs for each input image are saved in separate matrices.

Here, it is worth discussing the "tails" present on certain signs. Some signs, such as the larger variant of A1, "seated man" (), or most versions of I9, "horned viper" () (other than the version in *nfr*), can have a long tail, a stroke dragged down longer than what is typical for most glyphs.[187] This tail often intersects other glyphs or even other lines of the text. Although the interference of these tails for other glyphs has been removed in the processing of the data set (see above) and the tails have been isolated to their own glyphs, the tails drastically affect the aspect ratio of the signs for which they are present. Some I9 signs with a short tail are nearly horizontal, with an aspect ratio of perhaps 6:1. In contrast, the ones with a tail could have a wildly different aspect ratio (3:2, perhaps). This affects the aspect ratio filtering steps and, by extension, the analysis steps. This is only an issue if, as has been hypothesized by some, the tails are truly arbitrary and do not convey significant information.[188] In the interest of investigating this issue, the tails can be cut off artificially. This is not something that can be easily done by the program,

[187] Hoch, James E. *Middle Egyptian Grammar Sign List*. Mississauga: Benben Publications, 1998.
[188] Dr. Brian Muhs (Associate Professor of Egyptology, University of Chicago) in discussion with the author, November 2021.

given the variety of tail sizes and tail-like structures that should not be cut off. For instance, one would not want the program to chop off the right side of a V31, “basket with handle” (), sign, simply due to it looking tail-like.[189] It is not within the scope of this project to cut off every tail present in every sign, but a test data set was created manually, by horizontally cropping all A1 signs of the large variety (the form that can have a tail) at the lowest black pixel not in the tail. An example of this can be seen in Figure 2. This method ensured the preservation of the sign’s overall morphology, while also reducing the potential arbitrariness of tail length. This method is not perfect, but it is fully standardized and one of the only ways for all tails to be cut without introducing major human bias. Once a data set was created with the tails removed, the data set with tails and the data set without tails were then used for the program and their results were compared. In addition to allowing the best data set to be chosen, this is able to reveal information about the importance of tails. If the tail-less data set is better, then that lends evidence to the hypothesis that tails are arbitrary or at least partly so. On the other hand, if the data set with tails is better, then it may be the case that tails actually do contain significant information and more thought should be put into them in the future (see below).

Filtering by Fast Fourier Transform: After the filtering by aspect ratio, the remaining signs are filtered using Fast Fourier Transform (FFT). FFT computes the discrete Fourier transform (DFT) of a sequence which can then be compared to the DFTs of other sequences.[190] The DFT is, in essence, a number of frequencies decomposed from the original sequence (a frequency domain representation of the sequence). FFT reduces the complexity of the input and produces a much more quickly comparable output, allowing researchers to work with frequencies as easily and quickly as other types of data analysis. It is this aspect of FFT that makes it a staple in the fields of digital signal and image processing, including the encoding of MP3s, analysis of gravitational waves, and spectral analysis.[191]

To make the data usable by FFT, the saved vectors of pixel values are transformed into matrices, each matrix being of the same dimensions of the original image. For the simple 2x2 example given above, with a black top-left pixel, a white top-right pixel, a white bottom-left pixel, a black bottom-right pixel, and, thus, a vector of [0, 255, 255, 0], the matrix would be:

$$\begin{bmatrix} 0 & 255 \\ 255 & 0 \end{bmatrix}$$

The image matrices then undergo FFT using the np.fft.fft function provided by the NumPy Python package. It is not worth going into the math of this function here, but interested readers are encouraged to read Cooley and Tukey (1965).[192] This produces a complex matrix (the DFT) of both real and imaginary numbers of the same size as the input matrix. This is separated

[189] Hoch, James E. *Middle Egyptian Grammar Sign List*. Mississauga: Benben Publications, 1998.
[190] Cooley, James W., Peter AW Lewis, and Peter D. Welch. "The fast Fourier transform and its applications." *IEEE Transactions on Education* 12, no. 1 (1969): 27-34.
[191] Rockmore, Daniel N. "The FFT: an algorithm the whole family can use." *Computing in Science & Engineering* 2, no. 1 (2000): 60-64.
[192] Cooley, James W., and John W. Tukey. "An algorithm for the machine calculation of complex Fourier series." *Mathematics of computation* 19, no. 90 (1965): 297-301.

into two matrices, one real and one imaginary. The real and imaginary matrices for the input sign are compared to the equivalent two matrices for all of the saved candidate signs, a method that does not take a lot of time nor computing power. The FFT comparison algorithm is heavily inspired by the OCR work of Dr. Mark-Jan Nederhof.[193] Dr. Nederhof was kind enough to translate his FFT code into Python from Java and much of it did not need to be altered for this project. In this method, to compare two FFT outputs, a difference score is computed. This difference score is calculated as the absolute value of the input's real matrix (IReal) minus the data set sign's real matrix (DReal) at each value multiplied by a weight value plus the absolute value of the input's imaginary matrix (IImag) minus the data set sign's imaginary matrix (DImag) at each value multiplied by a weight value:

$$\sum_{i=1}^{20}\sum_{j=1}^{20}(|IReal_{ij}-DReal_{ij}|*Weight)+(|IImag_{ij}-DImag_{ij}|*Weight)$$

The above equation assumes an image size of 20 px x 20 px. If the images are a different size, the 20s are replaced with the image size.

The "Weight" value is determined by three factors: C, D, and g. Through testing and plotting of FFT spectra, it was determined that, for a resizing of 20, at points (5, 0), (10, 0), (11, 0), and (12, 0), hieratic FFT outputs are particularly variable across signs. Thus, more emphasis should be put on the differences found at those points. If the comparison is being made at one of those points, the program returns g as the weight. The variable g can be altered by the user, but, after many tests, it can comfortably be said that 1100 is the optimal value for g. If the FFT comparison is not looking at any of the previously mentioned four points, the weight value is set to equal D + (C-x) + (C-y), unless x or y is greater than or equal to C, in which case the weight is set to 0. The larger x and y are, the more of the DFT is being compared; thus, the choice of the value of C determines the number of frequencies being compared. D is purely a constant to adjust the weight further. The optimal values of C and D for this program have been found to be the size of the resized images (in this case, 20) and 3, respectively. By using 20 for C, all of the frequencies of the images are compared, which is marginally slower, but also ensures all the variation is taken into account. A user can adjust the values of C and D as seen fit.

This FFT comparison algorithm results in a difference score for every candidate image from the data set compared to the input image. The lower the score is, the more similar the DFTs of the two images are. This can be seen by considering the outcome of comparing a sign against itself. All of the values of IReal and DReal would be the same and likewise for IImag and DImag. When plugged into the equation, at each position in the matrix, the result would be 0. Summed up, this would still be 0, the lowest possible score which corresponds to the most similar two images can be (identical). One can actually produce reasonable identification results with this method alone, but it is not accurate enough to be used for any real morphological comparisons, as two signs which visually do not look very alike could have DFTs that look more

[193] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).

similar, given that they are both just decomposed into frequencies. Therefore, this FFT algorithm is used as a second filtration step and images with FFT difference scores above a certain threshold are discarded from the candidate list for their respective input sign. This threshold can be adjusted by a user, but 9500000 has been found to be an optimal or near optimal value for maximizing speed while not sacrificing accuracy. This usually produces candidate lists in the low hundreds per sign, a very manageable number.

Image Distortion Model: After the data set signs have been filtered by aspect ratio and FFT, producing a slim candidate list, the candidate signs are directly compared to the input sign using an Image Distortion Model (IDM). Much like the FFT algorithm, this project's IDM algorithm is indebted to Nederhof's OCR work and his generosity in translating his code into Python.[194] Of course, his code had to be adapted to fit this new problem, but it, along with Keyser *et al.*'s work on IDMs, provided a significant basis for the IDM section of this project's code.[195] The IDM used for this project compares images by looking at various windows of a certain size between the two images, outputting a difference score. The difference score increases the farther the window has to move from its original spot to find a matching window.

As an example, if the window size was one, image one had a black pixel in the top left corner, and image two had a white pixel in the top left corner, then the window would shift by a certain amount in image two, still looking for a black pixel, and increase the difference score until it found one. Because one can shift the window in any direction, the lowest of these scores is taken once a match is found. The difference scores for every possible window between two images are then totaled up to find the overall difference score. This is the essence of the code, although the implementation is a bit more complex. Also of note are the cases where the window shifts to a location beyond the image's bounds. To prevent an error in these cases, all pixels outside of the bounds of the image are assumed to be white, given that the image is cropped to fit the entire sign within the bounds. Two images that are identical will never need to shift their windows to produce a match, so their difference score when compared to one another will be 0. The window size (the context) and the amount to shift the window during comparisons (the warp) are two variables that a user can adjust. Like the other variables, extensive tests were done to find the values that returned the highest accuracy. These are a context of 2 and a warp of 4. Practically, this means the window is of size 2 px by 2 px and it moves 4 px when warped.

Other comparative methods: An IDM was not the only method used for comparisons. An extremely simplistic algorithm was tried, comparing each pixel from an input image to the corresponding pixel in each data set image, producing a similarity score of what percentage of the pixels were the same. This is similar to the IDM and slightly faster, but it is far less accurate for in-depth comparisons. Two images that are otherwise identical, but one is slightly tilted, would be considered quite different by the simple algorithm whereas the IDM would rightfully

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[194] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).
[195] Keysers, Daniel, Thomas Deselaers, Christian Gollan, and Hermann Ney. "Deformation models for image recognition." *IEEE Transactions on Pattern Analysis and Machine Intelligence* 29, no. 8 (2007): 1422-1435.

figure out that they are very similar. This method, while not used for the results in this paper, will be made available for users to try if they would like.

Another method used was a machine learning model using TensorFlow's Keras API for deep learning in Python. This was largely done by adapting TensorFlow's image classification tutorial.[196] The image classifier was created using a sequential machine learning model. 80% of the data set was used to train the model and 20% was used to validate the model, testing its accuracy on unknown data. Many different versions of the model were tried, but all led to a similar outcome: the model was almost 100% accurate on the training data, but was only around 60% accurate on the validation data. This is a classic example of overfitting, where machine learning models are good at recognizing material they have already seen, but not good at predicting the identities of new data. However, in the case of the hieratic data set, this likely comes from the fact that there are numerous categories with only one or two signs in them. For instance, there is only one example of sign E17, "jackal" (), in the data set. If this sign was in the validation data set, the model would not have been trained on recognizing E17s and could hardly be blamed for getting the identity of the sign wrong when it did not even know what an E17 looked like. Despite the current inaccuracies, this machine learning model is extremely promising if more data were to be collected and added to the data set. The larger the data set, the better the machine learning model will be. Machine learning models are extremely powerful and are a burgeoning resource for future OCR work.

Sign identification: Once the IDM computes difference scores for each input sign compared to all of their candidate signs, the results are saved in a matrix, containing all of the candidate data set sign names and their respective scores. This matrix is then sorted so that the signs with the lowest scores appear at the top. The results for the whole set of input signs are saved in one dataframe which is exported as two .csv files; one contains the sign rankings and their difference scores and one contains just the sign rankings. These files comprise the data that has been analyzed for this project, which can be analyzed, plotted, and compared, as well as the rankings that will identify a sign for a user. An excerpt of a larger .csv results file is given in Figure 3. For more information on the format of these files, see Table 4 below.

Data Analysis

The first investigation into the data that was performed was a comprehensive look at the program's accuracy. To evaluate accuracy for any given set of data, the .csv file containing just the ranked signs is loaded into Python as a dataframe. The first row of the dataframe, containing the names of the input files, is isolated and the specific sign represented by each file is saved ("A1_0021_1_2_9.png" is saved as "A1"). Then, the program can check if that sign appears in the filenames of any number of top choices in its respective column of the dataframe. After this is done for the whole input, accuracy can be calculated by dividing the number of times the sign did appear in the results by the total number of signs. In other words, each original input sign's

[196] "Image Classification: Tensorflow Core." *TensorFlow Tutorials*. https://www.tensorflow.org/tutorials/images/classification.

true value is compared to the signs in a determined number of top choices given by the OCR program and the number of correct results is tallied and divided by all of the signs to determine the ratio of correct identifications:

$$\frac{\text{signs for which at least one of the top } x \text{ signs were correct}}{\text{total signs}} = \text{accuracy ratio}$$

The number of top signs (x) for which this is computed are one, two, and ten. Each accuracy ratio is then multiplied by 100 to produce a percentage accuracy.

The above accuracy determination method was done for data from single signs, but it was also done for random samples of the data, to gauge the accuracy of the program on data at large. These random samples were produced from the overall data set using NumPy's random.choice function with replace = False. Another random sample, only drawing from the data set signs with greater than one example in the data set, was also taken. This was done in the same way, but after counting the examples present for each sign and filtering the signs with single examples out. Accuracy values are provided in Table 6 below.

Before any further analysis could be done on the OCR results, the .csv files had to be put in a distance matrix. As the name suggests, a distance matrix contains the distances between each sign in a set. To do this, first, the full .csv file, containing the sign rankings and their difference scores, is loaded into Python as a dataframe. From this, a list of all of the original input signs is saved and is used to make up the column and row names for a square distance matrix. Then, the matrix is filled in with the difference scores in the .csv file. If two signs do not appear in the output of the OCR program for each other (i.e. they were filtered out by aspect ratio or FFT), the overall difference score is taken as NA. If two signs do appear in each other's lists, the overall difference score is taken to be the sum of the two respective scores. Although this should only happen very infrequently, if one sign appears in another's list, but not vice versa, the existing difference score is simply doubled. To illustrate this method, a simple example of a possible result table and distance matrix for five signs is given below in Table 4: in red are the input signs, in blue are the ranked data set signs (in this example, the number of ranked signs is four or fewer, although it is usually in the hundreds for the real data), in yellow are the similarity scores for the signs to their left. There are a few NA values in this table to illustrate the fact that, in the real data, not every sign has the same amount of candidates that filter through the aspect ratio and FFT steps. This produces NAs in the real data as well.

Table 4: An example of a possible .csv output from the OCR program

Sign 1	Score	Sign 2	Score	Sign 3	Score	Sign 4	Score	Sign 5	Score
Sign 4	300	Sign 9	220	Sign 2	720	Sign 1	340	Sign 8	360
Sign 7	347	Sign 3	700	Sign 4	810	Sign 6	380	Sign 4	408
Sign 6	450	NA	NA	NA	NA	Sign 5	420	Sign 1	499
Sign 5	507	NA	NA	NA	NA	Sign 3	870	NA	NA

Table 5: The distance matrix produced from the example data in Table 4

	Sign 1	Sign 2	Sign 3	Sign 4	Sign 5
Sign 1	0	NA	NA	640	1006
Sign 2	NA	0	1420	NA	NA
Sign 3	NA	1420	0	1680	NA
Sign 4	640	NA	1680	0	828
Sign 5	1006	NA	NA	828	0

This distance matrix includes only the input signs and their difference scores when compared with one another. Even though, in Table 4, Sign 8 was the top choice for Sign 5, it is excluded because it is not within the input signs and is just a data set sign. In general, computing a distance matrix is only relevant or useful if one is interested in investigating the morphological similarities between a specific subset of the data set. Putting in a random sample from the data set produces a distance matrix of mostly NAs. It is also worth noting that the diagonal of zeros is the expected difference scores when signs are compared to themselves. Sign 1 compared to itself would produce a difference score of 0 and, in the distance matrix, 0 + 0 = 0. After the distance matrix is computed, the NA values are filled in because most algorithms that take a distance matrix as an input cannot deal with NA values. The NA values are replaced with the highest number in the matrix (in Table 5's case, it would be 1680). This replacement number could be any number greater than or equal to the highest number in the matrix and there would be no difference in results. It is purely a placeholder that communicates "these two signs are the most unalike in this set".

For this project, the main value of the distance matrix is that it can be used for UMAP (Uniform Manifold Approximation and Projection). UMAP is a non-linear dimensionality reduction technique that allows the simplification and analysis of high-dimensional data, while preserving the original structure of the data.[197] UMAP was created to allow for easy, fast, and intuitive analysis of large and complex data sets, such as this program's matrix of many signs, all with different similarities to one another. In brief, UMAP constructs a high-dimensional graph representation of the data and then creates a low-dimensional graph that is optimized to preserve as much of the global and local structure as possible. These graphs are influenced by the connectedness between data points; in the case of this paper's data, the connectedness between two points is represented by the distance, the sum of the difference scores. Although the theory behind UMAP is simple, the math is complex and interested readers are encouraged to read McInnes *et al.* (2018), the original publication of UMAP.[198]

UMAP was run using the "umap" package in Python and using the umap.UMAP.fit_transform function on the distance matrix. The UMAP output was then graphed using matplotlib.pyplot. For an input (for instance, every example of A1), usually four UMAP plots were made, all identical except for the colors. One was colored by facsimile maker, one was colored by provenance, one was colored by genre, and one was colored by text. These identifications were extracted from the filename tags described in Table 3. Due to the time constraints of this work, only a few signs were able to undergo the whole analysis pipeline outlined above. Some of the most interesting/variable signs were chosen to be looked at, as well as some of the most common signs. All of the UMAP plots that were created are given in Appendix 4. A link to a GitHub repository with the code used for this project is given in Appendix 3.

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[197] Coenen, Andy, and Adam Pearce. "Understanding umap." *Google PAIR* (2019).
[198] McInnes, Leland, John Healy, and James Melville. "Umap: Uniform manifold approximation and projection for dimension reduction." *arXiv preprint arXiv:1802.03426* (2018).

Results and Discussion

This section of the paper will present a variety of results of the OCR analysis on the data set, mainly consisting of UMAP graphs and their possible interpretations. Readers are encouraged to view the figures and the Appendix 4 figures and draw their own conclusions as well. As with the previous section, below is a list of subsections to enhance the ease of reading:

1. *Program Accuracy*
2. *Sign Distinguishing*
3. *Tail Separation Investigation*
4. *Facsimile Maker Investigation*
5. *Shipwrecked Sailor and Papyrus Prisse Investigation*
6. *Lahun Texts Investigation*
7. *Text Genre Investigation*
8. *Papyrus Westcar Investigation*

Overall, the data set that has been produced for this project, made up of individual, ligatured, and intersecting characters from the Poe, Möller, and Tabin facsimiles, cut out by Sobti and labeled with their Gardiner sign code, is extremely large. The data set is 13,134 characters, providing a fantastic starting data set for OCR, the largest of its kind in the field. For reference, Franken and van Gemert only used about 4000 images for their 2013 hieroglyphic recognition paper.[199] The data set used in this project contains 1,104 distinct character classes, including unique ligatured and intersecting signs. 341 different hieratic signs, categorized by Gardiner's sign codes, appear in the data set, either individually or in ligatures.[200] Some hieratic signs appear many times, such as A1, N35, and G1, while some only appear once or not at all. The signs that appear only a few times are not able to give much morphological insight by themselves, but they should still be identifiable by the program, unless they look identical to a more common character.

Program Accuracy

On average, the IDM model, when given a random sample of 500 signs from the data set, correctly identifies unknown signs in its first choice by difference score with 71.2% accuracy, in its top two choices with 78.5% accuracy, and in its top ten choices with 84.8% accuracy. In this test, each sign is excluded from the data set when it is compared, otherwise the program would get them all right as its top choice, as they would have a difference score of 0 when compared to themselves. These accuracy values seem a bit low at first glance, but one must keep in mind that, if a sign only shows up once in the data set, it will not be correctly identified when it is removed from the data set and input into the program. When excluding signs of this nature, the model is 74% accurate in its top choice, 81.8% accurate in its top two choices, and 88.2% accurate in its

[199] Franken, Morris, and Jan C. van Gemert. "Automatic Egyptian hieroglyph recognition by retrieving images as texts." In *Proceedings of the 21st ACM international conference on Multimedia*, pp. 765-768. 2013.

[200] Gardiner, Alan H. *Egyptian Grammar: Being an Introduction to the Study of Hieroglyphs.* 3. ed., Oxford: Griffith Institution, 1957.

top ten choices, a slightly better result. The accuracy values expected when using the program on new data are certainly even higher, being brought down in these tests because of irregular writings of certain signs which do not have a second example in the data set.

For signs for which there are a decent amount of copies, the accuracy increases even further. For example, for G1, the model is 94.5% accurate in its top choice, 96.3% accurate in its top two choices, and 98.2% accurate in its top ten choices. A variety of accuracy values are given in Table 6. The accuracy of this program compares favorably to other such programs. Franken and van Gemert report accuracy scores of around 85% in their paper on hieroglyphic recognition and Nederhof reports accuracy scores of 91.3% for his program's top choice and 95.5% for his program's top two choices in his paper on recognition of Sethe's glyphs.[201,202] For most signs for which there are multiple examples, the program outlined in this paper has extremely high accuracy, a significant feat given the issues hieratic poses to OCR. The program's overall accuracy being lower is not concerning, given hieratic's immense variability and numerous uncommon characters, including ligatures and overlaps. The high accuracy for common signs also indicate that the program can be used for morphological comparisons and that it has the requisite fineness to do so. The program's accuracy on all data types would only be improved with a larger data set.

Table 6: Accuracy values for the IDM program

Input	Accuracy in 1 choice	Accuracy in 2 choices	Accuracy in 10 choices
500 random signs from the data set	72.200%	80.000%	86.000%
A different 500 random signs from the data set	70.200%	77.000%	83.600%
500 random signs from the data set, excluding those that have only one example in the data set	74.000%	81.800%	88.200%
Every A1 sign	91.376%	94.128%	96.147%
Every A2 sign	94.079%	97.368%	98.684%
Every D21 Sign	72.747%	85.275%	97.143%

[201] Franken, Morris, and Jan C. van Gemert. "Automatic Egyptian hieroglyph recognition by retrieving images as texts." In *Proceedings of the 21st ACM international conference on Multimedia*, pp. 765-768. 2013.
[202] Nederhof, Mark-Jan. "OCR of handwritten transcriptions of Ancient Egyptian hieroglyphic text." *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond*, Leipzig (2015).

Every G1 sign	94.505%	96.337%	98.168%
Every V28 sign	77.124%	91.503%	97.386%
Every X1 Sign	69.296%	83.239%	97.183%

Sign Distinguishing

As expected, given the accuracy values, the OCR program is quite good at distinguishing between signs that are very morphologically dissimilar. An example of this is given in Figure 4 and Figure 5. Figure 4 displays two signs, Aa1, “unclassified/placenta?” (𓐍), and A2, “man with hand to mouth” (𓀁).[203] These signs were chosen for demonstration purposes, due to the significant differences in form between them, as well as their relative abundances in the data set. The two specific signs in Figure 4 are both from Möller’s facsimile of Papyrus Prisse and are reasonable representatives of what those signs tend to look like.

Figure 5 displays a UMAP graph of the output of the program for all Aa1 and A2 signs in the data set. For this graph and all subsequent UMAP graphs in this thesis, each point represents one sign from the data set. In addition, the units of the graph’s axes are largely irrelevant, given that they are a result of UMAP’s graphical optimization and are a condensation of many dimensions of the data. In UMAP graphs, it is most important to focus on which points cluster with others. Because of how UMAP uses local distances to influence the creation of the graph, the absolute distances between global clusters should not be relied upon in an interpretation.[204] Also, since UMAP has some stochasticity in the creation of its graphs, if one were to rerun the code used to produce the plots in this thesis, there would be some minor, insignificant differences in the plots, mainly in the data’s rotation on the plots’ axes. All the conclusions in this thesis are the result of running the UMAP code many times, making sure any result is not just an outcome of the stochasticity, something unlikely to happen in the first place. For Figure 5, one can see that the Aa1 signs (in blue) clearly cluster together separately from the A2 signs (in orange). This striking separation is good evidence that the program is accurately distinguishing the two signs.

However, one may notice that there are two Aa1 signs clustering with the A2 signs in Figure 5. One of these signs is Aa1_0009_1_4_12, shown in Figure 6. This sign and the other Aa1 sign that clusters with the A2s are both correctly identified as Aa1 by the program in its top choice. However, they are from the Rhind Mathematical Papyrus, which has a distinctive style for Aa1 signs that is different from the usual writing, shown in Figure 4. Although a human might decide that the Aa1 in Figure 6 looks more like the Aa1 in Figure 4 than the A2 in Figure 4, this is not at all obvious to the program. Because the Aa1 cluster and the A2 clusters are so dissimilar, the UMAP algorithm opts to put the two outlier Aa1s in the A2 cluster because it recognizes more similarities. This provides a useful and important insight into the limitations of this OCR program. The program does not look at brush strokes or theoretical features, such as curves versus lines, as a human might; these features would immediately make it clear that the

203 Hoch, James E. *Middle Egyptian Grammar Sign List*. Mississauga: Benben Publications, 1998.
204 Coenen, Andy, and Adam Pearce. "Understanding umap." *Google PAIR* (2019).

Rhind Aa1s are more similar to the typical Aa1s, rather than A2s. Instead, the program takes a global morphological approach that is free of preexisting bias, for better or for worse; it simply looks at shape alone. The type of errors in clustering that are present in Figure 5 should not happen often, unless very distinct signs with a few outliers each are compared. Nevertheless, anyone using this program should be aware that the program may provide slight errors in these cases.

In Figure 7, a UMAP plot is provided for A1 (in blue) and A2 (in orange). Examples of A1 are given later in this section in Figure 12. Here, one can see that there are still fairly distinct clusters, but there is more overlap and the clusters are closer together than in Figure 5. This makes intuitive sense, given that the two signs are much more similar in general form to one another than Aa1 and A2. This plot has been provided to demonstrate that the closer two signs are morphologically, the less distinct the UMAP clusters will be.

This UMAP cluster comparison can be used to investigate questions relating to signs that can look nearly identical to the human eye. For example, D21, "mouth" (𓂋), and X1, "loaf of bread" (𓏏), are often indistinguishable from one another.[205] For a scholar reading a hieratic text, these signs usually have to be determined through context clues or known spellings of particular words, rather than direct morphology. This similarity can be seen in the accuracy of the OCR program on D21 and X1 above in Table 6. Although the accuracy is over 97% for each sign in 10 choices, there is only around 70% accuracy in the top choice alone. This is due to the signs being so similar that the program initially sometimes misidentifies an X1 as a D21 and vice versa (of course, sometimes the program misidentifies these signs as other similar looking signs too). A variety of different writings of X1 and D21 signs from the data set are shown in Figure 8. The examples were chosen to demonstrate the signs' similarities to one another, but they do represent the variations in the two signs fairly well.

From the physical appearance of X1 and D21, it seems as if the two signs are written in effectively the same way. However, this is measurably false; Figure 9 shows a UMAP plot for X1 and D21. Here, although there is overlap between the two signs and there are not very distinct clusters, it is clear that D21 and X1 do segregate apart from one another overall. Indeed, even the accuracy values support this. Since X1 and D21 are being correctly identified in the program's top choice 70% of the time, there must be significant differences overall. If there were not and the signs were effectively identical, the program would be expected to identify the signs correctly 50% of the time only. Given that the program demonstrates that there are differences between X1 and D21 in general, future work can be done into exactly what elements of the signs distinguish them from one another. This is a limitation of the OCR program: it can inform which signs are similar/different, but not what specific features make them so. The data on which X1s cluster with D21s and which do not can be extracted from the UMAP output and another program could be written to investigate the specific features that separate the two signs. This is beyond the scope of this work, but would be a fascinating follow up experiment.

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[205] Hoch, James E. *Middle Egyptian Grammar Sign List*. Mississauga: Benben Publications, 1998.

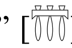
A similar analysis to the above was done on O49, “a town’s crossroads” (⊗), and N5, “sun” (☉).[206] In hieroglyphs, O49 generally appears after city-related words and place names, whereas N5 generally appears after sun-related words and date/time words. However, for hieratic, the signs are often indistinguishable and are only determined by context, much like X1 and D21. Figure 10 displays a UMAP of O49 and N5 and, unlike the previous comparison, there is no clear separation. This is supported by the accuracy values: for O49, the program is 25% accurate in one choice, 35% accurate in two choices, and 65% accurate in ten choices; for N5, the program is 31% accurate in one choice, 45% accurate in two choices, and 76% accurate in ten choices. These are very atypical and low accuracy values and, while they would likely increase with greater sample size, it demonstrates that O49 and N5 both look so much like other signs that they often cannot be distinguished from them.

Certain writings of O49 and N5 are identified by the program not only with one another, but also with Aa1, D21, D32 (𓂡), N33 (𓏌), W24 (𓏊), X1, Z1 (𓏤), Z4 (𓏭), and more. In this light, the high similarity between the writings of O49 and N5 is probably not a reflection that those signs were similar in some deeper way to the Egyptians. Instead, it is a good demonstration of a common theme in hieratic: small determinatives losing detail. Modern readers are surely not the only ones who used context to determine signs; the Egyptians were likely doing that easily when reading and writing hieratic. Thus, they could write different determinatives exactly the same without worry. D32, N33, W24, Z1, and Z4 are all small determinatives that follow words, so it is no wonder that there is overlap between the cursive forms of these small signs that have similar uses. In addition, Aa1, D21, and X1 are all common signs with simple writings, so it is unsurprising that the simplified determinatives sometimes look like them.

This analysis gives an insight into two things. 1. If, in hieratic, many determinatives are collapsed into a common form so completely, it is hard to make the case that determinatives continue to carry much meaning at this stage of the language (Middle Egyptian), at least the most common ones. By the Middle Kingdom, the determinatives seem to be an established convention for how to write each word, but, unlike “determinative” suggests, do not assist in helping a reader determine the category of a word. If a circular writing after a word can mean O49, N5, D32, N33, W24, Z1, Z4, or more, then it cannot be that helpful in distinguishing the word. Although the determinatives are much clearer in hieroglyphs, if they were actually significantly helpful in determining a word, they would also be clear in hieratic. 2. As mentioned above, the OCR program can only distinguish between different shaped signs. Identical signs will lower the accuracy substantially. If two signs look identical, the program’s accuracy will be 50% in one choice. If three signs look identical, the accuracy will be 33% in one choice and so forth. The small determinatives are a great example of an area where the program is limited in identification ranking. On the other hand, large comparisons through UMAP are not limited in this way, as the difference score is the important part, not the exact ranking.

It should be noted that, while UMAP comparisons can be extremely useful, they, like many analyses, suffer when sample size is low. Another comparison was attempted between F31

[206] Hoch, James E. *Middle Egyptian Grammar Sign List*. Mississauga: Benben Publications, 1998.

("three foxes' skins tied together" []), S15 ("a piece of jewelry?" []), W11 ("ring-stand for jars" []), and W17 ("water amphorae in a rack" []).[207] Unfortunately, the numbers of each sign in the data set were far too low to accurately distinguish anything. A UMAP is provided in Figure 11, but the structure of the plot is cloud-like and the points are almost equally spaced. This could indicate that there is little difference in the form of the four signs or it could indicate an underlying structure that the plot cannot demonstrate well. Although the signs do look somewhat similar, nothing conclusive can be said without more information. This underscores the importance of having a large data set. With less common signs, comparisons can be difficult or even impossible. This can be ameliorated if more signs are added to the data set over time.

Tail Separation Investigation

Within single signs, there can still be a large amount of variation. A1, "seated man" (), is a good example of this. There are multiple writings of A1, but they generally fall into two main groups: hereafter called "large" and "small". A typical example of each is shown in Figure 12. The two types of A1 are quite distinctive and some texts use both versions to represent A1. Within this project's data set, the texts that include large A1s are Shipwrecked Sailor, Eloquent Peasant B1, Sinuhe B, and Texte aus Hatnub. The data from Papyrus Prisse also includes one large A1.

Figure 13 is a UMAP plot of the two variants and, as one might expect, they largely cluster separately. There are a few examples of small A1s clustering with the large A1s, but this could be explained by two factors. First, as mentioned above for Figure 5, unique writings of signs could be misidentified by the program if they are different from both main groups. This could make sense in this example, as it is more likely a small A1 would be drawn with some extra projection that would make it look like a large A1 than a large A1 somehow being written in a condensed way to look like a small A1. Second, what is a "large" A1 and what is a "small" A1 was determined manually, introducing human error. Some signs theoretically could have been misidentified at the first step. This is another utility of the program outlined in this paper; it can be used as a check to make sure identifications are correct. In any case, Figure 13 is unambiguous in demonstrating that the two variants of A1 are largely distinct.

However, there is more to the variation in A1 than purely small versus large. The large A1 signs have a great amount of variance with respect to tail length. Tails, described above in the "**Filtering by aspect ratio**" section of the "*The Comparison (OCR) Program*" section of the "Methods" section, are long strokes dragged down beyond the normal extent of a sign. These strokes, hypothesized to be arbitrary, significantly affect the program's comparisons.[208] An example of the tail variation in large A1 signs is provided in Figure 14. The red line indicates the start of the tail as decided by the method described above.

Figure 15 shows a comparison between the UMAP plot of the large A1s on their own (a.) and those same large A1s, but with all of the tails cut according to the above methods (b.). The

[207] Hoch, James E. *Middle Egyptian Grammar Sign List*. Mississauga: Benben Publications, 1998.
[208] Dr. Brian Muhs (Associate Professor of Egyptology, University of Chicago) in discussion with the author, November 2021.

points are colored here by their original text. With the tails intact, the signs from different texts cluster together with one another in certain places. When the tails are removed, suddenly the clustering happens strongly by text. This clustering by text is not always the case for signs (see below), so it indicates that the A1 shape is very distinctive between different handwritings. In addition, since the removal of the tails prompted the clustering to be by text, rather than dispersed with little rhyme nor reason, this is good evidence that tails are fairly arbitrary. No one author is lengthening the tails in a distinctive way.

This is further demonstrated by the Hatnub data; the Hatnub signs should always cluster on their own, apart from the other texts, given that the Texte aus Hatnub are carved hieratic instead of written and, thus, have significantly different morphology. The Hatnub data is an ideal outgroup and it offers a way to evaluate the quality of the results. In the graph with the tails, one of the Shipwrecked glyphs clusters with the Hatnub material, a very strange occurrence and likely due to the similarity in tails driving the comparison, rather than the rest of the character shape. When the tails are removed, the Hatnub glyphs cluster together without any other texts, as expected. This is further evidence that the tails are not good elements to include when trying to use signs for comparisons, as they can overwhelm better indicators of the underlying sign morphology. Overall, this investigation offers striking evidence of the arbitrariness of sign tails, at least for A1 signs. It seems that the tails are only added when convenient and little meaning is encapsulated by their length or inclusion at all. Far more significant is the body of each sign as an indicator of handwriting or text. In the future, similar work should be done cutting the tails of other signs to see if these results are more widely applicable.

The data clustering by text when the tails are removed leads to another interesting observation: Sinuhe B and Eloquent Peasant B1 largely cluster separately. This is interesting because there is evidence that those two texts were written by the same scribe.[209] Supporting that hypothesis, most of the time Sinuhe B and Peasant B1 glyphs cluster together (see Appendix 4). In this light, it is quite interesting to see that, for A1, the two texts cluster apart from one another. Some A1 signs from Sinuhe B cluster with the Peasant B1 signs, but there is still a significant difference between the two that must be dealt with. These differences cannot be due to handwriting (because they were written by the same scribe), location (because they were found in the same place), or time period (because they were written at roughly the same time). There are a few possibilities, however.

One possibility is that the difference could be due to a difference in genre/person; both are literary texts, but the Eloquent Peasant is a mostly third-person narrative with poetic elements and Sinuhe is a first-person narrative written in a journal style. Thus, there could be an as-of-yet unknown difference in writing styles between these two texts. This is especially compelling because, in Middle Egyptian, A1 can represent the first-person singular suffix pronoun (𓀀) and it is also included in the first-person singular independent pronoun (𓏌𓎡𓀀). In these uses, A1

[209] Parkinson, Richard B. and Baylis, Lisa. *Four 12th Dynasty Literary Papyri (Pap. Berlin P. 3022-5): A Photographic Record*. Berlin: Akademie Verlag, 2012.

would be particularly important for first-person narratives, like Sinuhe.[210] Sinuhe also clusters closest to Shipwrecked Sailor, another first-person narrative which would use A1s in a very similar way. In fact, the Shipwrecked Sailor cluster has two distinct groups within it, one closer to Sinuhe B and one farther away. This could represent the difference in first-person Shipwrecked A1s as opposed to other usages of A1 in the text. In this case, the first-person Sinuhe A1s would be clustering with the Shipwrecked first-person A1s and the non-first-person Sinuhe A1s would be the ones clustering with the Eloquent Peasant A1s. In essence, this would mean that there is a difference across different texts in the convention for how the first-person A1s are written. Unfortunately, it is beyond the scope of this project to analyze the use of each of these signs. However, the program has been set up to make such comparisons trivial, provided someone collects the data. In the future, one could record the usage of each A1 (first-person pronoun or not) and add a tag to the end of all of them in the same way the text or facsimile maker is recorded in the current data set. Then, it would be a simple click to add those colors to the UMAP and investigate this question.

Another possibility for the Sinuhe-Peasant A1 difference seen in this data could come down to writing implements. Although the scribe who wrote Sinuhe B and Peasant B1 likely used a similar brush for both, it is not at all out of the question that there were slight differences in the scribal utensil between the writings of the texts. This could have led to most signs being largely the same, but certain brush strokes appearing different. It could be the case that the large A1 sign includes some of the different brush strokes. This would be a tough hypothesis to test, but a finer look at the ink on the papyri could shine some light on it. However, this idea is perhaps only worth looking into if the previous hypothesis about A1 morphology being different for first person uses is found to be unsupported.

Facsimile Maker Investigation

Because the data set includes signs from multiple facsimiles of texts (Möller, Poe, and Tabin), questions about the quality and accuracy of facsimiles can be investigated. If a facsimile maker has a very distinctive style that overwhelms the underlying variation between the texts, one would expect their signs to be clustered separately from the rest of the data in a UMAP plot. On the other hand, if the three facsimile makers had the exact same handwriting and style, then one would expect the signs to not cluster based on maker at all. Beyond that, one would expect two data set signs that come from different facsimiles of the same text (i.e. are facsimiles of the same sign) to have a difference score of 0 and overlap completely in a UMAP plot. This can be looked at because, as mentioned above, the Poe and Tabin facsimiles overlap to a certain degree for the Shipwrecked Sailor text and the Möller and Tabin facsimiles overlap to a certain degree for the Peasant B1 text.

Figure 16 is a UMAP plot of the output of the program for all D21 signs in the data set. In this figure, the plot is colored by facsimile maker. D21 was chosen as an example, but all

[210] It is worth mentioning that, for the suffix pronouns and the independent pronoun, both the large and small A1s can be used.

other signs tested produced similar results with regards to facsimile questions (see Appendix 4). In this plot, two interesting observations are immediately apparent. First, none of the facsimile makers' signs cluster separately from all the others, a good sign for the accuracy of the three facsimiles. In addition, there are some places in the plot where two differently colored points are extremely close to one another. Sometimes, this is due to very similar writings, but many of these places are where Möller and Tabin or Poe and Tabin made a facsimile of the same sign and they are correctly clustering close together. However, no two points are ever completely overlapping. This is a reflection of their difference scores not being 0 and, thus, the facsimile maker adding extra variation. Overall, the results indicate that, while there is some effect of the handwriting of facsimile makers, the driving factor of the clustering is the underlying hieratic morphological variation from the original texts.

In the interest of answering a likely question, it should be noted that there are isolated patches of blue and green points because Möller and Tabin respectively made facsimiles of signs/texts that no other facsimile maker in this study did. However, that does not explain the isolated patch of orange points, corresponding to signs from Poe's facsimile. Poe's facsimile does not cluster separately, but it also does not line up completely with the Tabin facsimile. Because the Tabin Shipwrecked Sailor facsimile covers all of the signs that Poe's does, ideally each of Poe's signs should be right next to one of Tabin's, if there was little effect of the facsimile creator. This is true for many of them, but not all, and it is the case for every plot of results from the data set, no matter the sign. Poe's facsimile was created more as a teaching tool than for morphological accuracy, but maintains the general shape of all of the signs. This leads to another interesting finding: most of the clustering can be explained by the general shape of the original signs. The little bit of clustering that the Poe signs do together is due to the more minor variations between facsimiles. In other words, Poe's loss of morphological accuracy in the fine details does have an effect, but not a significant one.

This finding is not necessarily unexpected; it does not take much to predict that variations in general shape, which are larger physical changes than those in minor details, will have a greater effect on similarity than the variations in minor details. Nevertheless, this has implications for the program and for facsimile creation. It has been shown that the program is fine-tuned enough to recognize small morphological changes between signs. If it was not, the Poe signs would not have grouped together. Therefore, the limits of the technology and the data set have not been reached, so even more complex facsimiles could be analyzed in the future. It is also clear that large scale comparisons can still be done on facsimiles that maintain the general structure of the original signs, but do not try to be 100% accurate. Of course, the more accurate a facsimile is, the better, but facsimiles with lower accuracy can still be useful, provided they adhere to overall morphological shape.

Shipwrecked Sailor and Papyrus Prisse Investigation

Another possible utility of the OCR program discussed in this thesis is determining the provenance of texts. Because each sign is tagged with the provenance of its original text, potentially the provenance of texts of unknown origin could eventually be determined through sign morphology. However, most of the texts currently in the data set are from Thebes and the rest of the texts with known provenance are either from Lahun or Hatnub. This is hardly a comprehensive library of signs from across Egypt. Due to the Theban overrepresentation in the data set, most unknowns will naturally cluster with Theban signs, but that does not necessarily indicate that they come from Thebes. The only telling thing would be if signs from a particular text did not cluster with Theban signs at all, but this is not the case for any of the texts of unknown provenance in this data set. With more data from more locations, location clustering could be a powerful tool, but it is beyond the scope of the current work.

Nevertheless, there are other ways to use the program to investigate provenance. In 1999, von Bomhard posited that Papyrus Prisse and Shipwrecked Sailor were in the same handwriting based on character similarities between the writing in Papyrus Prisse and the horizontal lines of Shipwrecked Sailor.[211] The similarity of these two texts was also noted by both Golénischeff and Möller.[212,213] If the two texts were in the same hand, then it is likely that the provenance of the Shipwrecked Sailor is the same as Papyrus Prisse: Thebes. However, although von Bomhard presents a compelling selection of signs where the Shipwrecked Sailor and Papyrus Prisse have similar writings, there are two limitations to this method. For one, only one or two examples of each sign are shown. Even though they are meant to be representative, the choice of which signs to take from each text for comparisons could still be subject to human bias. In addition, circularly, the signs that are easiest for a human to compare between the texts will be the ones that are most visibly similar. Signs that are distinctly similar are interesting and support two hands being the same, but more significant would be even the basic signs, without obvious identical quirks, being similar. This is a perfect application of the OCR program. The obviously similar signs can be compared on a large scale in a more comprehensive way and the less obvious signs can be investigated to see if they also support the hypothesis of a similar hand.

Two groups of signs were looked at in my analysis: one group were those that von Bomhard singled out as being similar between the two texts (A1, A24, D2, I9, N35_I9 ligature, V28, and Y1) and the other group were those which are fairly common and that von Bomhard did not cover in the 1999 article (A2, Aa1, D21, G1, M17, N35, and Z1). Although all of the Shipwrecked Sailor glyphs are present in the data set, only a few hundred Papyrus Prisse glyphs are in the data set. Thus, not all of the signs that von Bomhard specifically notes can be examined. The signs in each group were only chosen if there were at least a few examples present in the data set from both Shipwrecked Sailor and Papyrus Prisse.

Figure 17 shows a UMAP graph for A1 signs, with only Shipwrecked Sailor (red) and Papyrus Prisse (orange) colored. The section of Papyrus Prisse used for the data set only includes one large A1, so the small A1s are the more important part of this graph (the large top right cluster). Because the small A1s are the focus, there was no need to worry about the length of the

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211 von Bomhard, Anne-Sophie. "Le conte du naufragé et le papyrus Prisse." *Revue d'Égyptologie* 50 (1999): 51-65.
212 Golénischeff, W. *Les Papyrus Hieratiques No 1115, 1116A et 1116B de l'Ermitage Imperial a St Petersbourg*. St Petersburg: Ermitage Imperial, 1913.
213 Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1

large A1 tails. It can be seen from the graph that all of the Prisse A1s cluster with the Shipwrecked A1s. In addition, while there are a few Shipwrecked A1s that do not quite cluster with the others (ignoring the large A1s and their tails), that can be explained by the variation within the text and, if Shipwrecked Sailor was written in the same hand as Papyrus Prisse, one would expect there to be fewer outliers if Papyrus Prisse was added to the data set in its entirety. For all of the other signs that von Bomhard mentions that were testable, the results are largely the same. The UMAP graphs of them can be seen arranged in Figure 18. Even for signs like D2 and V28, where all of the Prisse points do not nicely cluster together, indicating multiple ways the scribe wrote the signs, there are still always Shipwrecked points close by. For I9, there is a lot more variation in the Shipwrecked Sailor signs, but one must keep in mind that the text was written both horizontally and vertically, whereas Papyrus Prisse was only written horizontally. This could have an effect on any sign and could explain some of the extra Shipwrecked Sailor variation seen in some of the other graphs, but it would be especially significant for signs with long tails, like I9. For the signs von Bomhard selected, the OCR program confirms the observation that the handwriting of Papyrus Prisse and that of the Shipwrecked Sailor match up very closely. In fact, as seen earlier in this results section, not many texts actually use the large A1 character and, since both Papyrus Prisse and Shipwrecked Sailor do, their link is strengthened.

For the more common signs that von Bomhard, Möller, and Golénischeff chose not to or were not able to directly compare between Papyrus Prisse and Shipwrecked Sailor, the pattern still holds. Figure 19 is a UMAP graph for D21 signs, again with only the glyphs from Shipwrecked Sailor and Papyrus Prisse colored. D21 does not visually stand out as being similar between the two texts because large-scale variation in D21 is harder to see with the human eye due to how common D21 is and how variable it is even within texts. However, much like the other signs, the Prisse D21s are always distributed near the Shipwrecked D21s, across the wide range of variation in D21. This shows that not only do the D21s of the two texts cluster together all the time, but that they have the same spread of variation. There is no region in the graph where a Papyrus Prisse glyph is far away from a Shipwrecked Sailor glyph and clearly clustering apart. There are some examples of Shipwrecked glyphs doing this, but that is again expected given that Papyrus Prisse is not fully digitized in the data set and that some of Shipwrecked Sailor is vertical. The same results appear in the other signs analyzed for this group, shown in Figure 20. All of them have the Prisse glyphs clustering strongly with the Shipwrecked glyphs. The graph with the weakest association is that of M17 and, even there, the association is quite strong. It is worth noting that no other text's glyphs associate so strongly with Shipwrecked Sailor's for almost every sign. For more information, the reader is encouraged to view this paper's Appendix 4.

Since almost every single sign holds the pattern of Papyrus Prisse clustering significantly with Shipwrecked Sailor,[214] this is strong evidence for the claim that Papyrus Prisse and

[214] An observant reader will see that sign V30, a UMAP of which is provided in the appendix, has some overlap between Prisse and Shipwrecked, but there is also some significant divergence between the texts for that sign. However, this is not a true problem for the theory that the two texts were written in the same hand. One can see that,

Shipwrecked Sailor are in the same hand and, thus, the provenance of P. Hermitage 1115 is Thebes. This analysis shows the immense power of the OCR program to make wide-reaching comparisons and determine scribal hands or provenances. Of course, this is only confirming an already established and largely accepted hypothesis, but these kinds of comparisons will lead to more and more interesting new findings as the data set size increases, furthering the paleographic power.

Lahun Texts Investigation

The analysis done for the Shipwrecked Sailor and Papyrus Prisse comparison was done from a "bottom up" approach, where similarities were seen between signs and then the hypotheses were tested on the larger data set using the program. The program is also very proficient at a "top-down" approach, where the UMAP results can indicate text similarities and specific signs that are worth looking into. This can be demonstrated through a look at the results for the Lahun material. Three Lahun texts are represented in the data set: the Hymn to Senwosret III, the Will of Wah, and the Temple Files. Of the three texts, the Hymn has the most signs in the data set and the Temple Files have by far the least.

Before any analyses can be done, the question must be asked: "is there a 'Lahunian identity' in the texts?". In other words, one must determine whether or not the scribes from Lahun have a common writing style. If not, then not only would it be difficult to compare the Lahun material to other locations, but it would also raise concerns about the validity of the idea that certain locations have distinguishable writing conventions. To help answer this question, signs were run through the program that had known examples from the three Lahun texts. The resulting graphs fell into two main categories. The first category is represented by Figure 21, a UMAP graph of sign V30, "basket" (𓎟).[215] Here, although there is a reasonable sign spread for the Hymn (light blue), the Will (light green), and the Temple Files (magenta), it is clear that they are mostly clustering together. Even in the cloud-like UMAP projection for this sign, there is good evidence that, for V30, all the Lahun texts have quite similar morphology. This type of observation holds true for Aa1, D2, and M17, to various extents (Figure 22). The associations for some of these, especially Aa1, are not very close, but the signs are still in the same region of the graph and are provided for a reader to get a fuller picture of the variety from sign to sign.

Much more common is the second category observed, into which all of the other signs tested fall. An example of this category is sign V28, whose UMAP is displayed in Figure 23. For V28's UMAP, there is an area with significant overlap between the Lahun texts, but they do not overlap everywhere. There are places in the graph with a few isolated points from either the Hymn or the Will that have no other Lahun points near them. This underscores the difference between the personal handwritings of certain scribes and commonalities in the handwritings within locations. Using a "scribal school" framework, it could be the case that scribes in a certain

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even for texts known to be in the same hand, such as Peasant B1 and Sinuhe B, there is still divergence at times (Figure 15). This could be due to differences in scribal implement, in age/experience of the scribe when they wrote the different texts, in genre, or in words in which the signs appear.

[215] Hoch, James E. *Middle Egyptian Grammar Sign List*. Mississauga: Benben Publications, 1998.

location learned their school's way of writing specific signs, but that, as scribes began encountering new words and learning on the job, they picked up other ways of writing signs too.[216] If that model is true, then the cluster with blue, green, and magenta at the top of the graph in Figure 23 represents the common writing of the school/location and the other clusters represent the hands of the specific scribes. The two Lahun texts with many signs, the Hymn and the Will, have vastly different genres and would perhaps have been written by different scribes with different specializations, so the lack of overlap in the non-common area is unsurprising. With any singular sign, one will often find some overlap between the writing of certain texts, so many signs need to be viewed to investigate this. A1, D46, I9, N35, X1, Y1, Z1, and Z2 all show this pattern to varying degrees (Figure 24).[217] However, due to the limited number of signs for which two or more of the texts had multiple copies, the sample size of signs that were able to be viewed in this way is not high.

Altogether, it seems that there is reasonable evidence that the Lahun texts have some commonality to them that can be explained by their provenance, particularly for certain signs like V30. This is a good indication that, with more data from more locations, the program will be useful for comparing provenance information and that certain locations do have hallmarks of their writing style. Continuing this top-down approach, one can look at potential similarities between specific texts as well. Figure 25 displays a UMAP for G1, colored by Lahun text. G1, "Egyptian vulture" (), would fall into the second category described above: signs where there are places of Lahun text overlap, but not everywhere.[218] The most interesting area of the graph is the small cluster of signs at the top that are separate from the rest of the plot. That small cluster includes only Lahun signs. The only other cluster like this is on the top left, composed of only Hymn signs. Clearly, there are two unique Lahun writings of G1, one from the Hymn and another present in all three Lahun texts. Observations of this type can be used as a starting point for more in-depth research.

While the program does not say what features specifically differentiate signs, it is not difficult in cases like this to find which signs are significantly clustering apart, as they should be clearly visually different. If one looks at the variation in G1s present in the Hymn to Senwosret III, one can immediately see the outliers. Figure 26 shows a comparison between an example of an unusual G1 from the Hymn and a G1 from the Hymn that looks like a typical G1 from most texts. This atypical writing of G1 in the Hymn was noticed by Möller as well.[219] The differences are staggering; the unusual G1 has two curved lines going up as opposed to the typical single one and another horizontal line is added above the two. This writing is very distinctive of the Hymn, appearing four times, but it also appears a few times in Sinuhe, Möller describes.[220] None of the atypical Sinuhe G1 glyphs happen to be included in the program's data set, since Möller did not

[216] Williams, Ronald J. "Scribal training in ancient Egypt." *Journal of the American Oriental Society* (1972): 214-221.
[217] As noted above, I9's data should be taken with a grain of salt, given the variable and possibly arbitrary tail lengths.
[218] Hoch, James E. *Middle Egyptian Grammar Sign List*. Mississauga: Benben Publications, 1998.
[219] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1
[220] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1

make a facsimile of the sections of Sinuhe in which they appear, so that is why there are no Sinuhe glyphs in that separate cluster in the plot. This observation leads to many interesting avenues for further research into the distribution of the atypical G1 sign: why does it appear only in Sinuhe and the Hymn? In what contexts is it used versus the normal writing, given that both texts use both variants?

As for the other isolated G1 cluster, Figure 27 shows the typical Hymn G1 compared with this other atypical G1 writing from the three Lahun texts. Again, the differences are immediately apparent and striking. This atypical G1 is written in a z-shape with a straight bottom, as opposed to the normal G1's two humps at the bottom. The single Hymn G1 from this cluster, displayed in Figure 27, seems like an intermediate form between the usual shape and the z-shape and, although it clusters with the z-shaped G1s, it is obviously not quite the same, still maintaining the two-humped base. Much like the case of the other atypical G1, all of the texts in which these G1s appear use a mixture of both the usual and unusual forms and this can be seen in Figure 25. However, since the Will z-shaped G1 and the Temple Files z-shaped G1 are so unique and are so similar, the possibility is raised that these texts were written by the same scribe. In addition, Möller gives examples of variants of the z-shaped G1 from a couple other texts, but the only other text with z-shaped G1s that look even remotely similar is Sinuhe once again.[221,222] Thus, there are two new questions for the program to weigh in on: 1. Could the similarities between the atypical signs indicate any link between the scribe of Sinuhe and the Lahun scribes? 2. Were the Temple Files and the Will of Wah written by the same scribe?

Dealing with the latter of the two questions first, the Temple Files and the Will of Wah do seem to cluster together significantly more than either of them do with any other text, including the Hymn. Looking at the UMAP plots with multiple points from each of the two texts, patterns can be looked for. A reader is encouraged to view the plots in these figures (and in Appendix 4) and draw their own conclusions, but, in this author's opinion, the two texts are very strongly similar. As with Shipwrecked Sailor and Papyrus Prisse, there are far more data points from the Will of Wah than the Temple Files, so the full range of writings of each sign are likely not captured from the Temple Files, or even the Will, for that matter. In any case, given the higher number of signs from the Will, one would expect the Will to have more variation, whether or not the two texts were written by the same hand. The plot for G1 is a perfect example of this; the Will and the Temple Files overlap in a significant way, apart from all other texts (except for a stray Hymn sign), but there is also a bit of extra variation in both texts. The plot for V30 (Figure 21) has the two texts clustering next to one another with almost all of the variation in each matched by the other. This is similar for M17, X1, and Y1 to certain degrees (Figure 22, Figure 24). Another strong piece of evidence is that the plot of Z2 shows the Temple Files and the Will clustering together at the top, with only one sign from each text clustering in a separate section of the plot (Figure 24). Even signs for which the two texts cluster less closely, such as Z1 (Figure 24), do not discount the theory, given that even texts which are known to be written by the same

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221 Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1
222 As before, the data set's limited coverage of Sinuhe led to the data set lacking the Sinuhe z-shaped G1s.

scribe do not always have overlapping signs (see Figure 15 b.) The evidence presented here is by no means conclusive that the Will of Wah and the Temple Files are written by the same scribe. The sample size is relatively low and the observations are purely visual, rather than statistical. However, there is a strong overlap between the two texts that goes beyond the explanation of their shared provenance; otherwise the Hymn would also cluster with them strongly, something that is clearly not the case, as in the plot for Z2. Therefore, these two texts should be investigated further and more rigorously. Additionally, these results could potentially indicate different scribal trainings for scribes of different types of texts, given that the Hymn is religious and the Will and Temple Files are more administrative. This is also a fascinating possibility. If more Lahun material is added to the data set, the power of these studies would only increase and this promising lead could be taken to its conclusion.

As for the other question, whether Sinuhe and the Lahun texts are related, the same plots as above can be created, but with the Sinuhe B and R texts colored as well. Figure 28 shows a number of these plots. Even a cursory look at these graphs makes it abundantly clear that neither Sinuhe text has any significant morphological relation to any of the Lahun texts. The Sinuhe texts always cluster apart from the Lahun material and, even when there is overlap, it is clearly nothing more than coincidental. This demonstrates that the program is not only good for validating hypotheses, but it can also provide evidence to the contrary and allow them to be checked in a way that a human could not do. This result also should offer comfort to a reader skeptical about the strength of the Will of Wah and Temple Files clustering; here it is shown what quite unrelated texts look like on the UMAP graphs and it must be admitted that the Will-Temple Files association is quite a bit stronger. Given that the Sinuhe texts and the Lahun texts do not seem to be related by overall scribal hand, another explanation must be given for the unusual G1s being present in those texts. However, that is beyond the scope of this work and is a question for the future.

Text Genre Investigation

Just as the program has been shown to be able to compare facsimile makers, provenances, and texts, one could also use it to compare the sign distributions across genres. Figure 29 shows a UMAP graph for sign D21, colored by genre. The genres of each text are given above in Table 2. Unfortunately, a familiar problem shows itself here: literary texts are overrepresented in the data set, in the same way as how Theban texts are overrepresented in the data set, making comparisons difficult. Although one can look at the UMAP in Figure 29 and attempt to draw some conclusions, it is hard to say anything definitive, because most of the genres represented in the data set have only one text. For example, the hymn genre's representation in the data set includes only the Hymn to Senwosret III. Thus, the distribution of the hymn signs in the genre map only gives information about the Hymn to Senwosret III, information that cannot necessarily be extrapolated to hymns in general. A reader intrigued by genre comparisons can find more examples of genre UMAPs in Appendix 4, but not much can likely be discovered about sign forms across genres yet. When more texts are added to the data set, these genre comparisons will not only become feasible, but will be very worthwhile.

Almost all of the UMAP plots colored by genre look similar to the plot in Figure 29. There are little to no discernable patterns to the distributions of signs from each genre and, even if there were, little could be said about them due to the limitations of the data set. However, one interesting pattern appears: the medical genre and the mathematical genre frequently cluster close together (Figure 29). Of course, the only medical papyrus in the data set is Papyrus Ebers and the only mathematical papyrus is the Rhind Papyrus, so, more accurately, the data is showing that specifically those two texts frequently cluster close together. This is intriguing, given that the provenance of both texts is unknown. It must be noted that strong clustering between these texts is very unlikely to indicate the same scribal hand and, thus, the same author, given that the two texts were almost certainly written over a hundred years apart.[223,224]

Figure 30 provides a number of signs for which there are multiple representatives from both the Rhind and Ebers texts. Looking through them, a couple patterns emerge. For signs like A2, Aa1, and I10, the Ebers signs cluster with themselves in one area and the Rhind signs do the same, but the two clusters are very close to one another. This shows that the two texts each have their own unique writings for each of the signs, but that their unique writings are close to each other's. For signs like D21, D46, M17, X1, and Y1, there is large amounts of overlap between the texts and, although the texts each have signs that are distributed in multiple parts of the graph, the variation in the texts is largely matched by the other. Not all the variation in one text is always matched by the other, but this is unsurprising given the very different contexts of the two texts and the limited amount of signs from each text that are in the data set. This pattern shows that the two texts have a range of writings of these signs, but their range is similar. For signs like G1, I9, V28, Z1, and Z2, there is still some important overlap between the two texts, but one or both of the texts has significant variation not seen in the other text. This could be due to the aforementioned limited number of signs from each text in the data set, but it could also be true variation that one text has that the other does not. This latter interpretation is not unlikely given how much extra variation is seen in some of these graphs.

Overall, the morphologies of a large number of signs show significant similarities between Papyrus Ebers and the Rhind Papyrus beyond what one would expect for two unrelated texts. Erman had mentioned the similarities between these two texts in 1890, but not to this degree.[225] This is good evidence that the OCR program can replicate conclusions made by previous research. However, not all of the signs of the two texts cluster completely, an expected result since they do not share an author and are greatly separated temporally. This result provides a good starting point for future work into why these texts have so many similarities. This could be due to the two genres (medical and mathematical) being similar, both being practical and

[223] Bryan, Cyril P. *Ancient Egyptian Medicine: The Papyrus Ebers (Translated from the German Version)*. Chicago, IL: Ares Publishers, 1930.
[224] Chace, Arnold B. *The Rhind Mathematical Papyrus*. Oberlin, OH: Mathematical Association of America, 1927.
[225] Erman, Adolf. *Die Märchen Des Papyrus Westcar: I: Einleitung Und Kommentar. II: Glossar, Palaeographische Bemerkungen Und Feststellung Des Textes*. Berlin: Spemann, 1890.

academic. One could investigate this by adding more medical and mathematical texts to the data set. The overlap could also be due to the two texts both being by scribes from the same scribal school, many years apart. This hypothesis would be harder to test, but, if it was supported, a great insight would have been gained about the continuity of sign forms over centuries in scribal schools. This is also not a far-fetched idea, given that both texts have been hypothesized to come from Thebes.

Papyrus Westcar Investigation

So far, this Thesis has discussed three out of the four unknown texts in the data set: the Shipwrecked Sailor, the Rhind Mathematical Papyrus, and Papyrus Ebers. There are various pieces of evidence indicating that all these texts are from Thebes, but nothing is absolutely definitive (see Table 2 and the "*The Texts*" section of this paper). For Papyrus Westcar, however, there are almost no leads at all for the provenance of the text. As stated above, the program does not have, at the moment, enough variety in text origins to determine provenances by clustering, except by specific hands, as in the case with Papyrus Prisse and the Shipwrecked Sailor. The above work on the Lahun hands does indicate that a common provenance identity can appear in the clustering, but that will only be useful for determining unknowns in the future, as the data set gets larger.

For now, the most useful thing to do is to see if Papyrus Westcar has a distinctive writing style. When trying to determine what is unique to a certain text, one should keep in mind that every text written by a single author will have its own way of writing certain signs. Thus, every sign run through the program can provide useful information. However, for maximum impact, it is worthwhile to look for signs where two things are true: the signs from the text in question cluster together and the cluster is apart from the majority of the data set. The first of these is important because not every sign in a text will have such a distinct way of being written, especially those that are common and simple, such as X1 or D21. Most of the time, such signs will have a wide range of variants and will not all cluster together. These signs are still useful when comparing texts to one another because not every text will have the same breadth of variants, but they are less useful on a first pass where one is just trying to acquire information about a single text. If all signs from one text cluster together, then one knows that there is a specific way that text always writes a certain sign. This is helpful information, but it is even more helpful if the sign clusters away from the rest of the data set, because that indicates that that way of writing that sign is unique to the text.

A few signs that were analyzed in this paper align with both of these outlined points. The first of these is V30, whose UMAP plot is shown in Figure 31. Although there are only three examples of V30 in the sections of Westcar used for the data set, they clearly cluster on their own and are significantly apart from all of the other V30 signs. If one takes a look at the Westcar writing of V30, one can see that Westcar creates the sign using three large strokes, as opposed to the typical four (Figure 32). However, Papyrus Westcar is by no means the only text to write V30 this way. The three-stroke V30 appears multiple other times in the data set, the most similar three-stroke version being from Papyrus Ebers (Figure 32). The Ebers V30s even cluster somewhat near the Westcar V30s, as one might expect (see V30 plots in Appendix 4), but the Westcar glyphs are still quite separate from the rest. Just by looking at the Ebers and Westcar V30s, it is not apparent to a human eye what the huge difference is. For example, Möller did not categorize this V30 writing as a separate variant, as he sometimes did with other unusual writings, so he clearly did not think there was a large difference.[226] This is the utility of the OCR program: it can lead to insights even in places where humans cannot see. Perhaps the thickness of the strokes for the Westcar V30 is what is leading to the separate clustering, but this seems unlikely to produce such a separation on its own. There is likely underlying morphology that is yet to be understood differentiating the Westcar V30s.

Another Westcar glyph that clusters separately, albeit not as starkly, is A2. A UMAP plot can be seen in Figure 33. The Westcar signs cluster together in the corner of the plot, except for a single outlier which is still quite close. Although this clustering is not apart from the rest of the graph like in the case of V30, it is still off to the side as opposed to being in the middle of the main plot, so it is worth being looked at. A2 is a sign with a decent amount of variation between texts, a fact discernable from the large separated clusters in the UMAP graph. Therefore, three signs have been chosen to non-comprehensively represent the variation in A2 in the data set for Figure 34. A model Westcar A2 is also displayed in the figure. At first, it seems confusing why the program separated the Westcar A2s, given that all of the features in the Westcar A2s appear to be in other A2s from the data set. The specific Westcar A2 in Figure 34 has a longer left hand loop than the other signs in the figure, but that does not hold for all the Westcar A2s nor all the data set A2s. A longer look at all of the Westcar variation produces the answer to the differential clustering: the "foot" of the sign on the bottom right is significantly truncated in all of the Westcar A2s compared to the data set glyphs. This holds true for all of the Westcar A2s and no other text in the data set comes close to having an A2 with as short a foot, except those without a separate stroke for the foot, such as the first example in Figure 34. Westcar's exceptional A2 writing was not noted by Möller in his paleography.[227] Again, the ability of the OCR program to quickly and accurately produce high quality observations based on large data analysis is demonstrated.

Although, in its current form, the program cannot concretely determine Papyrus Westcar's provenance, the above two examples with V30 and A2 have shown that the program is already apt at leading a scholar to interesting information about the distinctive morphology of its characters. There are surely more signs that would produce similar results that have yet to be investigated. In the future, if these writings of signs unique to Westcar are shown to appear in another text, insights into the provenance or even the specific scribal hand of the text could be gained. This section of the analysis shows the program's ability to supplement human-based paleographic methods. For instance, although one likely could have discovered the shortened feet of Westcar's A2s with extensive study, the OCR program provides an easy indicator of what

[226] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1
[227] Möller, Georg. *Hieratische Lesestücke für den akademischen Gebrauch*. Leipzig: Hinrichs, 1909. Vol. 1

signs one should pay attention to, significantly cutting the time needed for such work. In addition, the data set allows for quick comparisons across many different texts, circumventing the many hours needed to sift through texts looking for specific signs.

Conclusion and Future Directions

This paper has provided an overview and proof-of-concept for applying Optical Character Recognition methods to the field of hieratic paleography. A substantial data set of 13,134 individual signs from a range of texts, genres, and facsimile makers was created and an Image Deformation Model was used to analyze the signs. The program proved adept at quickly and accurately identifying individual signs, as well as making large scale comparisons. The sign identification element of the program will surely be a great benefit to scholars of all stages. Those who are learning hieratic will be able to use the program to check their own transcriptions and assist with recognizing difficult signs, as opposed to the old way of having to flip through Möller's paleography in the hopes of stumbling upon the desired sign. Even those who are well versed in hieratic will be able to benefit from the program's ability to recognize and separately cluster sign variants beyond the level of human perception.

As for the comparisons made possible by the program, there are infinite possibilities, only a few of which were able to be dealt with in this work. First, through a comparison of Aa1 and A2, the program was shown to cluster signs purely by shape, not by strokes as humans might. Then, a comparison of X1 and D21 showed that, although the two signs often look identical to humans, there is underlying morphology separating them. On the other hand, O49 and N5 were shown to often look effectively the same, underscoring the common trend of small determinatives being condensed and written the same in hieratic. F31, S15, W11, and W17 also were compared, but the data set did not have enough examples of each for the comparison to be very strong.

After this, the A1 data set was shown to segregate into large and small A1s. The large A1 data set was plotted with and without their tails. The plot without the tails was far superior and intuitive, demonstrating that the lengths of tails of signs are mostly arbitrary and do not convey significant information about handwriting. However, when the tails were removed, the Sinuhe B and Eloquent Peasant B1 texts clustered apart from one another, a curious finding given that they are known to be written in the same hand. It was hypothesized that the usage of the first person pronoun or variations in writing implement could account for this.

Through a look at the way signs do not seem to strongly cluster by facsimile maker, the program was also shown to truly be looking at the underlying sign morphology, for the most part. The texts that had facsimiles done by multiple facsimile makers had their signs cluster together as expected and no signs segregated by facsimile more than a bit. This reflects that, even if one is primarily concerned with general shape and not fine detail, such as Poe for his facsimile, such a facsimile can still provide useful information. In addition, it was extrapolated that the program's limits have not been reached and even more complex facsimiles could be analyzed in the future.

The program was also able to investigate an existing hypothesis that the Shipwrecked Sailor text is in the same hand as Papyrus Prisse.[228] Signs both that were previously pointed out by von Bomhard and those that were not so obviously similar were looked at. For almost every

[228] von Bomhard, Anne-Sophie. "Le conte du naufragé et le papyrus Prisse." *Revue d'Égyptologie* 50 (1999): 51-65.

sign, the Shipwrecked glyphs clustered with those of Papyrus Prisse, adding significant support to the hypothesis. This hand to hand comparison shows that the program is useful and proficient at answering such questions and can do so with significant ease and potential.

A similar comparison was done for the texts from Lahun, the Hymn to Senwosret III, the Will of Wah, and the Temple Files. First, it was determined that there is a common thread in the writing styles of the three texts, indicating a Lahun-specific scribal morphology and perhaps common training. Then, two unusual writings of G1 present in the Lahun texts were looked at. Stemming from this and other comparisons, there was preliminary evidence that the Temple files and the Will of Wah were written in the same hand, but more data would be needed to be sure. The atypical G1s also were seen in Sinuhe, but the Sinuhe texts were demonstrated to be clearly in a different handwriting.

The program, in its current form, was shown to be lacking when making genre comparisons, purely because the data set does not have multiple texts for most genres. However, from that analysis, it was shown that Papyrus Ebers and the Rhind Papyrus had very similar sign morphology. Although they are not the same handwriting, they do cluster close to one another quite frequently, perhaps indicating common scribal training or similarities between more practical text genres, like medicine and mathematics.

Lastly, Papyrus Westcar, famous for its unknown provenance, was looked at. Since the data set does not have a huge breadth of provenances, specific signs were identified as having writings unique to Westcar. The two signs with the most promising UMAP clustering were V30 and A2, the latter of which was shown to have a previously undescribed smaller foot. This demonstrates the program's ability to identify variable signs that humans have not. The program can sift through masses of data in an instant and also has a much finer ability to spot differences than any human could.

Overall, the various analyses performed in this thesis should offer a glimpse into the potential of the OCR program, both for learning and for research. In the future, this program can be improved to better support such uses. For the program itself, the three main sections of the pipeline (Sobti, the glyph labeling program, and the OCR program) can probably be combined into one streamlined program. This would be much more user-friendly and increase the accessibility of the tools. Sobti and the labeling program could also potentially use OCR to improve themselves, as mentioned above. This would minimize the need for manual input, other than to correct for errors the program makes in identification, further decreasing the time it takes for signs to be added to the data set.

Even before the above occurs, the data set, the various sections of the program, and the analysis code will all be made open-source for anyone to use, once they are in a workable and understandable condition. The code and data set images have been put onto a GitHub repository that is 100% accessible (see Appendix 3). The data set is able to be fully released because Möller's glyphs are no longer subject to copyright, Poe has authorized me to release his glyphs, and I will do the same for my own facsimiles. Because the data set and program will be free to use, anyone will be able to use the program to identify hieratic characters, allowing scholars to more easily read and learn hieratic. Because of the open-source nature of the program, it will be able to be adapted and expanded by anyone who is willing to contribute to the data set. As demonstrated time and time again in this paper, more data will lead to more comparative power, more findings, and more significance for research, not to mention vastly improving the already high accuracy of the program. In addition, data from more provenances, texts, genres, and facsimile creators will unlock numerous new possibilities for research, the beginnings of which were shown in this paper. All of the insights offered in the results section would benefit immensely from further research to test the hypotheses outlined here and to more completely understand the patterns observed.

Other data could be collected and added to the data set beyond what was explored in this thesis. One could add information on vertically versus horizontally written signs, because there are known differences in some sign shapes between the two formats.[229] It would be intriguing to see if the changes between vertical and horizontal are common across all texts or if some texts change different aspects of their writings. The methods used in the thesis could also be expanded to data from different time periods, to track the development of hieratic morphology over time. The texts in this thesis were almost all from around the Middle Kingdom period, to avoid adding an extra confounding variable. However, with much more data added, the time period of texts could go from being a confounder to being another axis from which one can make comparisons (see below). One could also add sign distribution and usage information, as suggested in the above discussion for the A1s from Sinuhe B versus Peasant B1. In addition, one could add texts from ostraca as well as papyri, given that some texts exist only on ostraca and the material is very different, possibly influencing the way signs are written.[230] A morphological comparison between the hieratic from ostraca and papyri on this scale would be very interesting.

As shown above, the program is able to investigate existing questions from the literature in the field. A few established questions and observations that the program could assist with are provided here:

- In his publication of Papyrus Prisse, Jéquier indicates that he believes that the final page was written hastily, due to the irregular line lengths contrasting with the remarkably consistent line lengths on the other pages.[231] Hagen, on the other hand, disagrees based on paleography, saying that the final page is written just as carefully as the rest of the text.[232] If all of the Prisse glyphs were added to the data set, one could test this easily. If the final page was written with less control, one would expect more variance in the signs from the final page. The Prisse signs should still generally cluster with one another, but, if the most variable Prisse signs are from the last page, then there is good evidence for Jéquier's

[229] von Bomhard, Anne-Sophie. "Le conte du naufragé et le papyrus Prisse." *Revue d'Égyptologie* 50 (1999): 51-65.
[230] Hagen, Fredrik. *An ancient Egyptian literary text in context: the instruction of Ptahhotep*. Peeters, 2012.
[231] Jéquier Gustave. *Le Papyrus Prisse Et Ses Variantes: Papyrus De La Bibliothèque Nationale (Nos 183 à 194), Papyrus 10371 ET 10435 Du British Museum, Tablette Carnarvon Au Musée Du Caire: Publiés En Fac-similé (16 Planches En Phototypie)*. Paris: Librairie Paul Geuthner, 1911.
[232] Hagen, Fredrik. *An ancient Egyptian literary text in context: the instruction of Ptahhotep*. Peeters, 2012.

claim. If the Prisse glyphs from the last page are indistinguishable from the others in their clustering, then there is strong support for Hagen's claim.

- The Maxims of Ptahhotep is a text that was copied many times over the centuries and there are known extant copies of the text from multiple different time periods, not to mention many texts for which there is hypothesized Ptahhotep influence.[233] There have been many studies on the word- and clause-level similarities between the various Ptahhotep copies, but sign-level similarities have been largely ignored thus far. If all of the signs from all of the Ptahhotep copies were added to the data set, the program would allow a comparison of these texts on a much finer scale than what has been done. Although the different scribes of the copies had different handwritings, it would be interesting to see if there was transfer of sign forms as the text was passed down and copied. If the signs from the Ptahhotep texts cluster closer to one another than one would expect for two unrelated texts, then that could be an indication that more than just the grammar and word composition was transferred, possibly changing how scholars think about ancient textual transfer.
- In many of his articles, J.L. Foster has furthered the idea of verse genres, including "narrative verse" (like the Story of Sinuhe), "lyric/hymnic verse" (like hymns), and "didactic/proverbial verse" (like the Maxims of Ptahhotep).[234,235,236] These are contrasted with other texts, written in prose, such as tomb autobiographies. However, these analyses have been restricted primarily to discussions of patterning of textual content: lines, couplets, clauses, and rhetoric. The OCR program can open a new door for prose versus verse comparisons. For example, it may be that certain sign forms are more common in one type of text. If, for instance, it was a convention for verse texts to have more detailed versions of a particular sign, this would be detected by the program. It is not at all implausible for texts that were already finely crafted in composition to also have been finely crafted in physical writing. The above investigation into sign tails clearly showed that A1 tails are arbitrary at the individual text level. However, this may not be the case at the verse versus prose level. Such questions remain to be investigated, but are well within the realm of possibility with this program. As more prose and verse texts are added to the data set, such analyses will become even more robust.
- As mentioned above, once more texts are added to the data set from different time periods, numerous avenues for future work will be opened. One such direction would be to investigate the date of Papyrus Westcar. Although much has been made of the lack of provenance information about the text, the date it was written is also by no means certain. Both the Eighteenth Dynasty and late Second Intermediate Period have been suggested as

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[233] Hagen, Fredrik. *An ancient Egyptian literary text in context: the instruction of Ptahhotep*. Peeters, 2012.
[234] Foster, John L. *Thought couplets and clause sequences in a literary text: the maxims of Ptah-hotep*. Toronto: Society for the Study of Egyptian Antiquities, 1977.
[235] Foster, John L. “"The Shipwrecked Sailor": Prose or Verse? (Postponing Clauses and Tense-neutral Clauses).” *Studien zur altägyptischen Kultur* 15 (1988): 69-109.
[236] Foster, John L. "Sinuhé: The Ancient Egyptian genre of narrative verse." *Journal of Near Eastern Studies* 39, no. 2 (1980): 89-117.

the date of creation.[237,238] While textual analysis and some paleographic methods have already been used to support these claims, the OCR program's powerful analytical abilities would be exceedingly useful in supporting or rejecting these hypotheses. It must be noted that hieratic variation need not be linear over time and one text clustering with another is not necessarily indicative of them being written in the same time period (see, for instance, the similarities established above between Papyrus Ebers and the Rhind Papyrus). Also, the two proposed dates are very close to one another and creating a distinction between the two time periods could be difficult, given the available texts. Nevertheless, the more texts that are added, the more informative these comparisons will be.

- Much like the other possibilities of discovering the provenances of texts of unknown origin, the program could investigate the origin of the Rhind Mathematical Papyrus. The findspot of the text is unknown, but it has been hypothesized to be Thebes.[239] However, even if that were true, that need not mean that the text was actually written in Thebes. The mention of a Hyksos king in the text has prompted some to suggest a Lower Egyptian origin for the Rhind Papyrus.[240] If there were more texts from the Hyksos time period and territory added to the data set, this could be looked into. Beyond the Rhind, more Hyksos texts would also allow for a Hyksos-Egyptian hieratic comparison. Since the Hyksos were foreign to Egypt when they took power, this could provide a fascinating look into the cultural transfer (or lack thereof) between the two groups on the level of text morphology.
- As previously mentioned, using paleographic methods, albeit old ones, Anthes indicated that the Middle Kingdom Hatnub graffiti seems quite similar to P. Berlin 10482, a copy of the Coffin Texts from Asyut.[241] More recent studies have not, to my knowledge, significantly followed up on this, but they have shown that P. Berlin 10482 bears similarity to other texts, such as P. Berlin 10480 and P. Berlin 10481.[242] Thus, there is plenty of data to use for the program and adding these data points would allow this question to be easily investigated. It could be that these P. Berlin texts are written in the same hand as the Hatnub quarry texts, but it also could be that these P. Berlin texts are simply written in a similar way to carved inscriptions, creating artificial similarity. Either way, the results would be interesting. There have been a number of dates proposed for the

[237] Parkinson, Richard B. *The Tale of Sinuhe and Other Ancient Egyptian Poems 1940-1640 BC*. Oxford University Press, 1997.
[238] Goedicke, Hans. "Thoughts about the Papyrus Westcar." *Zeitschrift für ägyptische Sprache und Altertumskunde* 120, no. 1 (1993): 23-36.
[239] Robins, Gay, and Charles Shute. *The Rhind Mathematical Papyrus. An Ancient Egyptian Text*. London: British Museum Publications, 1987.
[240] Spalinger, Anthony. "The Rhind mathematical Papyrus as a historical document." *Studien zur Altägyptischen Kultur* 17 (1990): 295-337.
[241] Anthes, Rudolf. "Die Felseninschriften von Hatnub nach den Aufnahmen Georg Möllers." *Untersuchungen zur Geschichte und Altertumskunde Ägyptens* 9 (1928).
[242] Regulski, Ilona. *Repurposing Ritual: Pap. Berlin p. 10480-82: A Case Study from Middle Kingdom Asyut*. Berlin: Walter de Gruyter GmbH, 2020.

P. Berlin 10480-2 texts and, if they are shown to be in the same hand as the reliably dated Hatnub quarry inscriptions, this could provide a solid answer to their date of origin. Of course, there are many possible issues with comparing typical hieratic to rock inscriptions, given the immense differences between their methods of creation, but these challenges could be overcome with large amounts of data and a keen eye for interpretation.

- Based on sign forms, the Edwin Smith Surgical Papyrus has been dated to the Hyksos period.[243] This is the same period as the Rhind Medical Papyrus, a fact that has not gone unnoticed in the literature. Similarities between the texts have been used to advocate for a concurrent dating for the two.[244] However, it has also been noted that Papyrus Ebers shares many resemblances to the Smith and Rhind papyri. This has led some to say that Papyrus Ebers should be dated to the Hyksos period as well. This is by no means the consensus view, but it is worth investigating further, given that the Hyksos dating is still being cited.[245] In this paper, the previously noted Rhind-Ebers sign similarities have been confirmed by the OCR program. I used this to spark discussion on common threads across genres and time periods, not to argue for an overlapping dating. Nevertheless, it would definitely be worth adding the signs from the Edwin Smith Surgical Papyrus to the data set. If the Smith Papyrus clusters more closely with the Rhind than the Ebers Papyrus, this would be good evidence for the common Hyksos dating of the former two and a separate dating for Ebers. This is the most likely scenario. On the other hand, if the Smith Papyrus clusters more closely with the Ebers Papyrus or equally with both, this should prompt further investigation into these dating questions.
- The Lahun papyri have been often categorized in various ways. Griffith proposed eight categories, ranging from "literary religious" to "healing" to "letters".[246] Maintaining these large categories, Quirke has categorized them within their "lots", the various individual deposits where the texts were found.[247] Although many take the concepts for granted, Quirke has challenged the notions of scribes, scribal education, and literary texts, pointing out that our modern conceptions cannot necessarily be applied. As demonstrated above, the OCR program can be helpful in determining scribal hands, as well as potentially genres. If one were to add all of the Lahun texts to the data set and then limit the comparison purely within the Lahun corpus, these questions could be investigated. For genres, even though Griffith's categories largely persist today in the literature, one could see if there is any segregation based on genre in Lahun and, if so, whether the genre clusters line up with what modern scholars would predict. If there are genre

[243] Allen, James P. *The art of medicine in ancient Egypt*. Metropolitan Museum of Art, 2005.
[244] Spalinger, Anthony. "Dates in ancient Egypt." *Studien zur Altägyptischen Kultur* (1988): 255-276.
[245] Quirke, Stephen. "Who Writes the Literary in Late Middle Kingdom Lahun?." *Problems of Canonicity and Identity Formation in Ancient Egypt and Mesopotamia* 43 (2016): 127.
[246] Griffith, Francis Llewellyn. *The Petrie Papyri: Hieratic Papyri from Kahun and Gurob (principally of the Middle Kingdom)*. Vol. 1. B. Quaritch, 1898.
[247] Quirke, Stephen. "Who Writes the Literary in Late Middle Kingdom Lahun?." *Problems of Canonicity and Identity Formation in Ancient Egypt and Mesopotamia* 43 (2016): 127.

conventions in character morphology, this would supply a window into ancient scribal education which was previously hidden. At the same time as the genre comparisons, the various scribal hands at Lahun could be looked at in the same way as in this study, but with far more power. These comparisons in tandem would give insight into questions such as:

  - How many scribes were at Lahun?
  - Did different scribes have different genre “specializations” and training?
  - What influenced the composition of the various Lahun text lots? Were they collected at all by genre or by author?
  - Would the Lahun text lots that modern scholars consider “mixed” in genre also be considered “mixed” by the ancient Egyptians?[248]

  The OCR program cannot completely answer all of these questions by itself, but it can provide a significant foundation for looking at them. Of course, many of these questions have been looked at before, but now, with OCR technology, they can be investigated to a far deeper level.

- It has been pointed out that hieratic in the First Intermediate Period seems to vary more by area and individual than in the Middle Kingdom.[249] This fact has been used to argue for decreased standardization within scribal education during this fragmentary period. Whether hieratic varies more in one era of Egyptian history compared to another is a question that is beyond the scope of most traditional paleographic studies. The amount of information needed to support such a claim with confidence is far greater than what one human could do on their own. Thus, studies to this point have had to mostly remain within the realm of the anecdotal. With the OCR program, one could easily compare thousands of signs from multiple periods in Egyptian history and calculate which signs vary more. This could be done by averaging difference scores among texts and, with the correct choice of texts, it would provide a statistical measure of variability. This measure would provide hard evidence whether First Intermediate Period hieratic is more variable than that of the Middle Kingdom. In addition, if this is found to be true, the claim that decreased standardization within scribal education is to blame for this can also be investigated. As described above, one could potentially use the program to distinguish scribal schools and this could be done within the data set for different periods. Potentially, one could even track specific schools throughout time by looking at clustering and see if they change in variability. This undertaking is wholly doable by the program, but would necessitate a vast number of texts from different periods to be added to the data set. Texts that are from the same places, but different time periods, as one another would be the optimal sources for this.

[248] Quirke, Stephen. "Who Writes the Literary in Late Middle Kingdom Lahun?." *Problems of Canonicity and Identity Formation in Ancient Egypt and Mesopotamia* 43 (2016): 127.
[249] Redford, Donald B, and Edward F Wente. “Hieratic.” Essay. In *The Oxford Encyclopedia of Ancient Egypt*. P-Z 3, 3:206–10. Oxford University Press, 2001.

- Building on the immediately previous point, investigating variation can also assist with other historical arguments. Möller identified that there were differences between Theban and Memphite hieratic since the start of the Nineteenth Dynasty.[250] The Upper Egyptian hieratic then deteriorated over time, leading to different cursive forms, and, ultimately, "abnormal hieratic".[251] With added data, these differences could be tracked through time and analyzed. This could lead to interesting studies related to the development of hieratic and even demotic. El-Aguizy has used comprehensive paleographical analysis to look at the possible connections between abnormal hieratic and demotic. This research could be made even stronger using the OCR program. The program should work just as well on a demotic data set prepared in a similar way to how the current data set was created. However, to use demotic, it would entail adding a vast range of demotic characters to the program, an undertaking that would be similarly, if not more, difficult than what is presented in this paper. The program is intended to be easy to use and supplement with more data, but adding demotic would require far more work and care. Even so, adding abnormal hieratic and demotic, along with other hieratic variants, would lead to fascinating insights.

For the program itself, a significant future direction for its development could be an alteration enabling the program to output information about what features of characters make them similar to one another. If that were the case, when the Westcar A2s clustered apart, a researcher would not have to guess about what feature of the sign caused the program to view them differently than the others. For A2 specifically, it was clear that the smaller foot was the issue, but it was not at all clear for Westcar's V30. The program could even highlight the exact pixels it notes as being different, creating a differential pixel heatmap. This method was beyond the scope of this thesis, but would not be too hard to do in the future and the technology is already available.

This pixel-highlighting method would also allow the OCR program to incorporate trajectory inference methods, much like what is done with single-cell RNA sequencing in biology.[252,253] In brief, single-cell RNA-seq data usually consists of the expression patterns of many genes for many individual cells from a sample. When analyzing RNA-seq data, UMAP graphs, like those in this thesis, can be made, with each point being a different cell. Clusters are calculated based on common gene expressions between cells and these clusters can be identified

[250] Möller, Georg. *Hieratische Paläographie: Die Aegyptische Buchschrift in ihrer Entwicklung von der Fünften Dynastie bis zur Römischen Kaiserzeit: III. Band: Von der Zweiundzwanzigsten Dynastie bis zum Dritten Jahrhundert nach Christ*. J.C. Hinrichs, Leipzig (1909).

[251] El-Aguizy, Ola. "A Palaeographical Study of Demotic Papyri in the Cairo Museum from the Reign of King Taharka to the End of the Ptolemaic Period." *Enchoria: Zeitschrift für Demostistik und Koptologie* 14 (1986): 67–70.

[252] Van den Berge, Koen, Hector Roux de Bézieux, Kelly Street, Wouter Saelens, Robrecht Cannoodt, Yvan Saeys, Sandrine Dudoit, and Lieven Clement. "Trajectory-based differential expression analysis for single-cell sequencing data." *Nature communications* 11, no. 1 (2020): 1-13.

[253] Wolf, F. Alexander, Fiona K. Hamey, Mireya Plass, Jordi Solana, Joakim S. Dahlin, Berthold Göttgens, Nikolaus Rajewsky, Lukas Simon, and Fabian J. Theis. "PAGA: graph abstraction reconciles clustering with trajectory inference through a topology preserving map of single cells." *Genome biology* 20, no. 1 (2019): 1-9.

as one tissue type or another using the gene patterns. If one creates a data set of many stages of development, such as Farnsworth *et al.*'s zebrafish embryo atlas, this can be taken even further.[254] Once clusters are made, since researchers know what time stage each cell is from, a developmental pathway from cluster to cluster can be distinguished. For instance, if a single-cell UMAP graph had three clusters of hematopoietic cells (a stem cell that can become any type of blood cell) from a young zebrafish, a juvenile zebrafish, and an adult zebrafish, a researcher would know which clusters are older and which are younger. The researcher could then look at the path along clusters from young to old, using trajectory inference methods, among others, to see how gene expression varies as the hematopoietic cells develop and differentiate over time. In other words, the researcher would be able to figure out exactly which genes differ between younger and older cells, how they differ, and if that progression is linear over a time gradient or not.

This method can absolutely be used for hieratic data. Each individual hieratic sign would be analogous to a single cell, the pixel composition would be analogous to the gene expression patterns, the sign identification would be analogous to the tissue type, and the period/dynasty a text was written would be analogous to the developmental stage. In this way, by using already dated texts, one would be able to use the program to accurately identify exactly what features of signs changed as hieratic developed, down to the pixel level. All this would entail is an adaptation of single-cell computational methods to use pixels instead of genes and an increasing of the data set beyond Middle Kingdom texts. Above, the addition of abnormal hieratic and demotic was mentioned as a possibility. Analysis of hieratic's possible development into and/or fusing with demotic would be a perfect application of these methods. This work is reliant upon more texts being added to the data set, but, if carried out, it would certainly be one of the most interesting outcomes of OCR as applied to Egyptian material, allowing a depth and scope of comparison reaching much farther beyond even the most ambitious current paleographical works, including this one.

Much further in the future, the program will hopefully be able to be used on direct images, rather than facsimiles. This would entail a much larger data set and far better papyrus images than what are often available. As explained at the beginning of this work, direct images are much harder to work with for hieratic given the variable amounts of papyrus damage, ink density, and other factors. However, a program specially created for this purpose, pre-trained on a myriad of facsimile images, could potentially work for that analysis. If this hypothetical future program incorporates machine learning techniques, which it certainly should as those techniques become exponentially more prominent and better, it could even accurately fill in damaged sections of papyri.

This paper has provided a strong starting point for future work in the fascinating and burgeoning field of ancient Egyptian Optical Character Recognition. The tools provided here will be instrumental for allowing scholars to tap into modern cutting-edge technological methods and

[254] Farnsworth, Dylan R., Lauren M. Saunders, and Adam C. Miller. "A single-cell transcriptome atlas for zebrafish development." *Developmental biology* 459, no. 2 (2020): 100-108.

apply them to new areas of research and learning. Over the course of this work, the point has hopefully been made that the current, human-driven paleographic methods can greatly benefit from the large-scale power of OCR technologies and that computer-driven methods can eliminate some of the bias that naturally enters paleographic work. These computer methods can distinguish morphologies of far more characters at once and to a far deeper level than any human can. It should be reiterated that the computer methods still require an Egyptologically trained hand to implement them, lest one makes incorrect interpretations of the data. This thesis ultimately provides more than just a proof-of-concept of OCR methods applied to hieratic. Here, a new technology has been adapted to the field and, as more people add to the data set and use the program, its usefulness will increase drastically. Artificial intelligence programs, like OCR, can no longer be ignored, especially as a new generation of motivated, technologically fluent scholars enter the field, ready to apply the most up to date methods. As we live through a time with an unprecedented amount of data at our fingertips, the ability to synthesize, categorize, and analyze that data in a controlled and advantageous way will become more and more important. For hieratic paleography, this thesis has provided the first step.

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Figures

Author's note: I am aware that a few of the figures have so many parts that they are almost unreadable in a printed format, where zooming in is impossible. To see the individual sections from such multi-part figures, see Appendix 1.

Figure 1: An example of the annotations done to prepare facsimiles for sign separation. This is Möller's facsimile of Papyrus Prisse 4, lines 1-4. The facsimile was color corrected to black and white before the five layers were added.

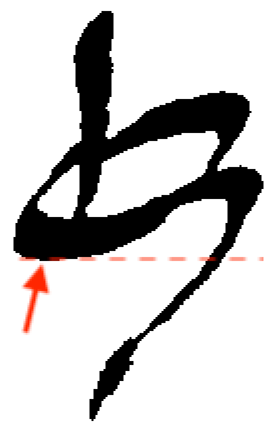


Figure 2: An example of an A1 and its tail. The red arrow points out the lowest black pixel not in the tail. The red dashed line indicates where the tail is cut. This sign comes from Eloquent Peasant B1.

Sign	Similarity Score	Sign	Similarity Score	Sign	Similarity Score
G1_0001_1_1_2	0	G1_0001_1_1_3	0	G1_0001_1_1_4	0
G1_0031_3_1_2	400	G1_0019_1_1_4	372	G1_0029_1_1_2	269
G1_0001_3_1_2	415	G1_0017_1_1_4	419	G1_0031_1_1_4	320
G1_0016_1_1_4	417	G1_0003_1_4_1	428	G1_0018_1_1_4	330
G1_0022_3_1_2	417	G1_0008_1_4_1	434	G1_0003_1_4_11	354
G1_0026_1_1_2	418	G1_0001_1_1_6	440	G1_0002_1_1_4	362
G1_0030_3_1_2	431	G1_0022_1_1_2	440	G1_0032_3_1_2	366
G1_0007_1_1_2	438	G1_0010_1_2_9	445	G1_0030_1_1_4	379
G1_0015_1_1_2	443	G1_0028_3_4_1	449	G1_0022_1_1_4	380
G1_0030_1_1_2	445	G1_0029_1_1_2	450	G1_0010_1_1_4	391
G1_0008_1_1_4	445	G1_0061_3_4_1	452	G1_0029_3_1_2	392
G1_0014_1_1_4	450	G1_0007_1_1_6	457	G1_0017_1_1_2	393
G1_0006_1_1_4	452	G1_0003_1_4_1	457	G1_0007_1_1_4	405
G1_0037_1_1_4	463	G1_0004_1_1_2	458	G1_0019_1_1_4	410
G1_0010_1_2_9	463	G1_0005_1_1_3	460	G1_0005_1_1_4	412
G1_0006_3_1_2	465	G1_0016_1_1_4	465	G1_0005_3_1_2	421
G1_0010_1_1_2	467	G1_0013_1_1_4	466	G1_0034_1_1_4	422
G1_0013_1_1_4	475	G1_0018_1_1_4	467	G1_0015_3_1_2	425
G1_0009_1_1_4	478	G1_0010_1_4_1	467	G1_0003_1_1_4	427

Figure 3: An example of a .csv file resulting from the program. This is the first 20 rows and 6 columns of the results for the G1 signs in the data set. The first, third, and fifth columns each correspond to the results for a different sign (given in the second row of each column). The second, fourth, and sixth columns display the similarity scores for the sign to their left.

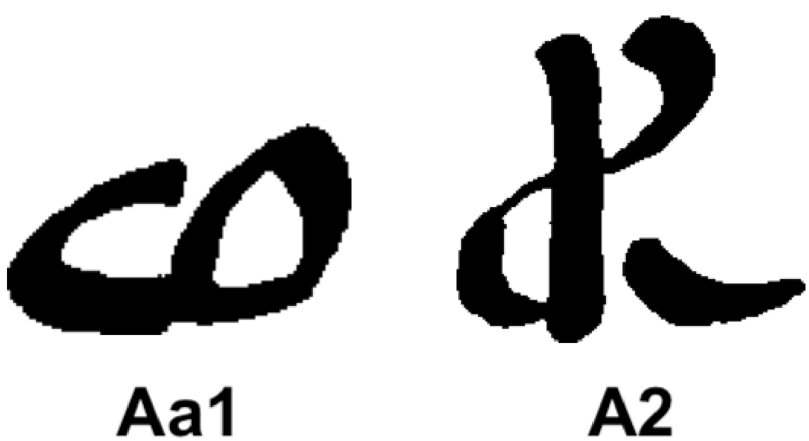


Figure 4: A typical example of an Aa1 sign (left) and an A2 sign (right). Both signs are from Papyrus Prisse.

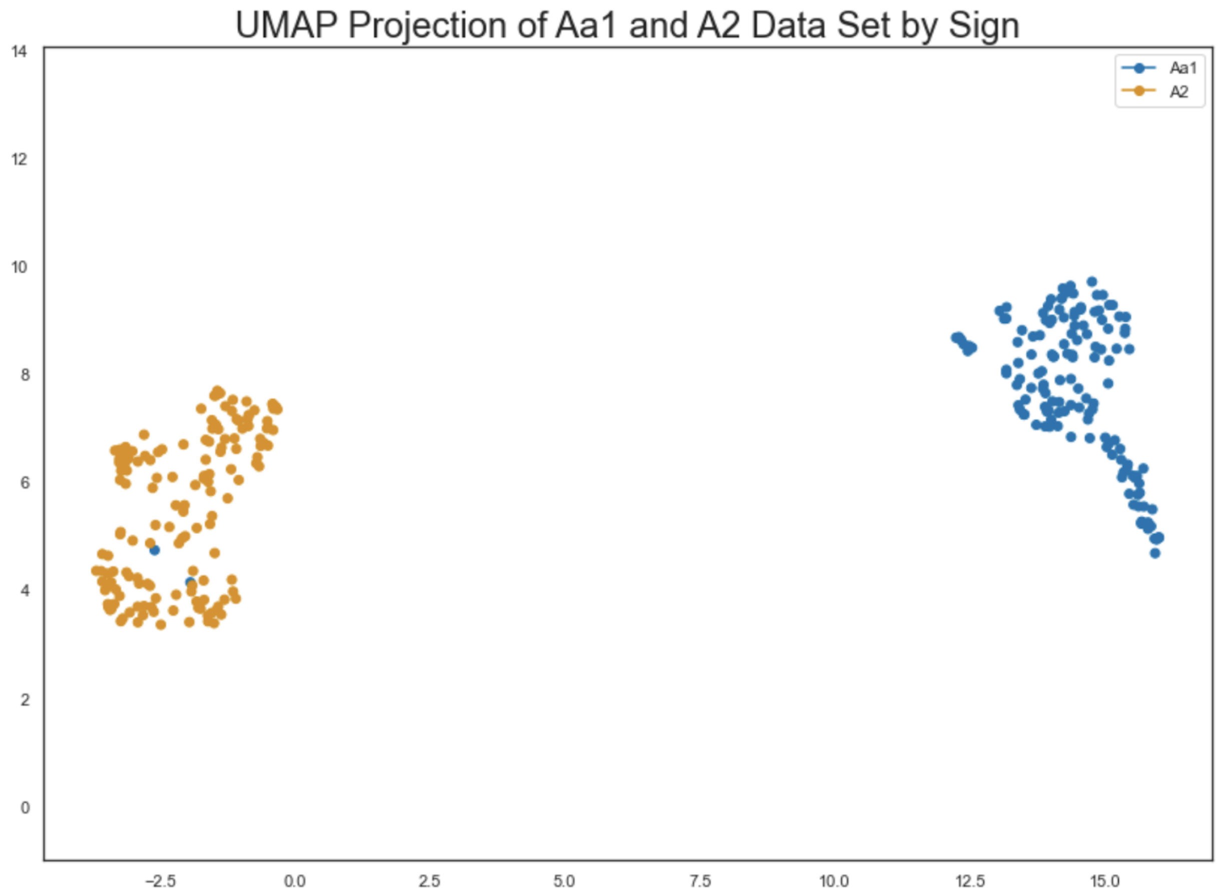


Figure 5: A UMAP plot of every Aa1 and A2 sign from the data set. Aa1 signs are in blue and A2 signs are in orange.

Figure 6: An example of an atypical Aa1 sign from the Rhind Papyrus.

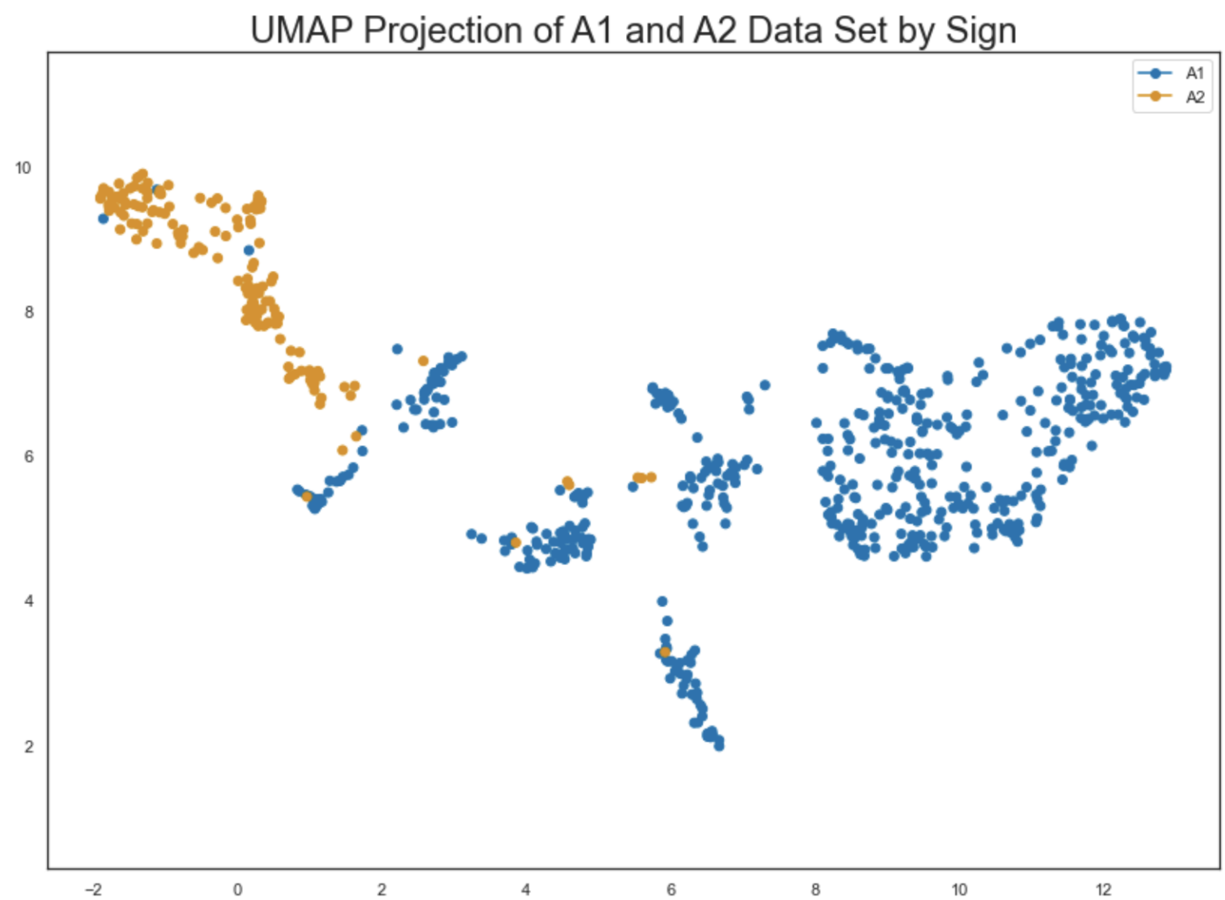


Figure 7: A UMAP plot of every A1 and A2 sign from the data set. A1 signs are in blue and A2 signs are in orange.

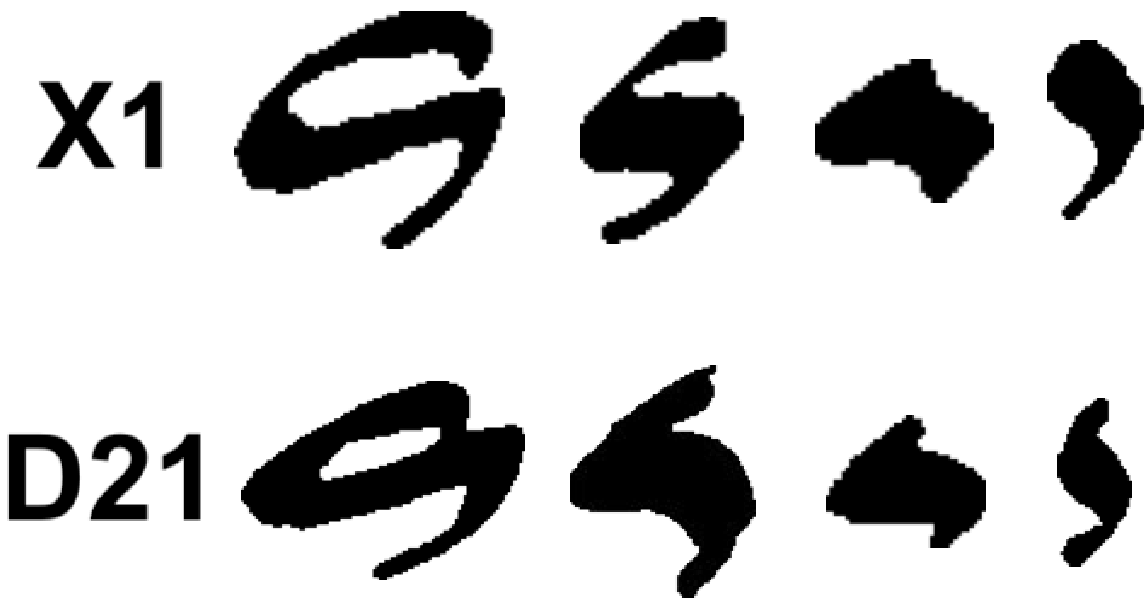


Figure 8: Four examples of X1 signs (top) and D21 signs (bottom). The examples represent the typical variation in these signs. The X1 signs come from, in order of left to right, Papyrus Ebers, Eloquent Peasant B1, Hymn to Senwosret III, and Eloquent Peasant B1. The D21 signs come from, in order of left to right, Papyrus Prisse, Eloquent Peasant B1, Hymn to Senwosret III, and Sinuhe B.

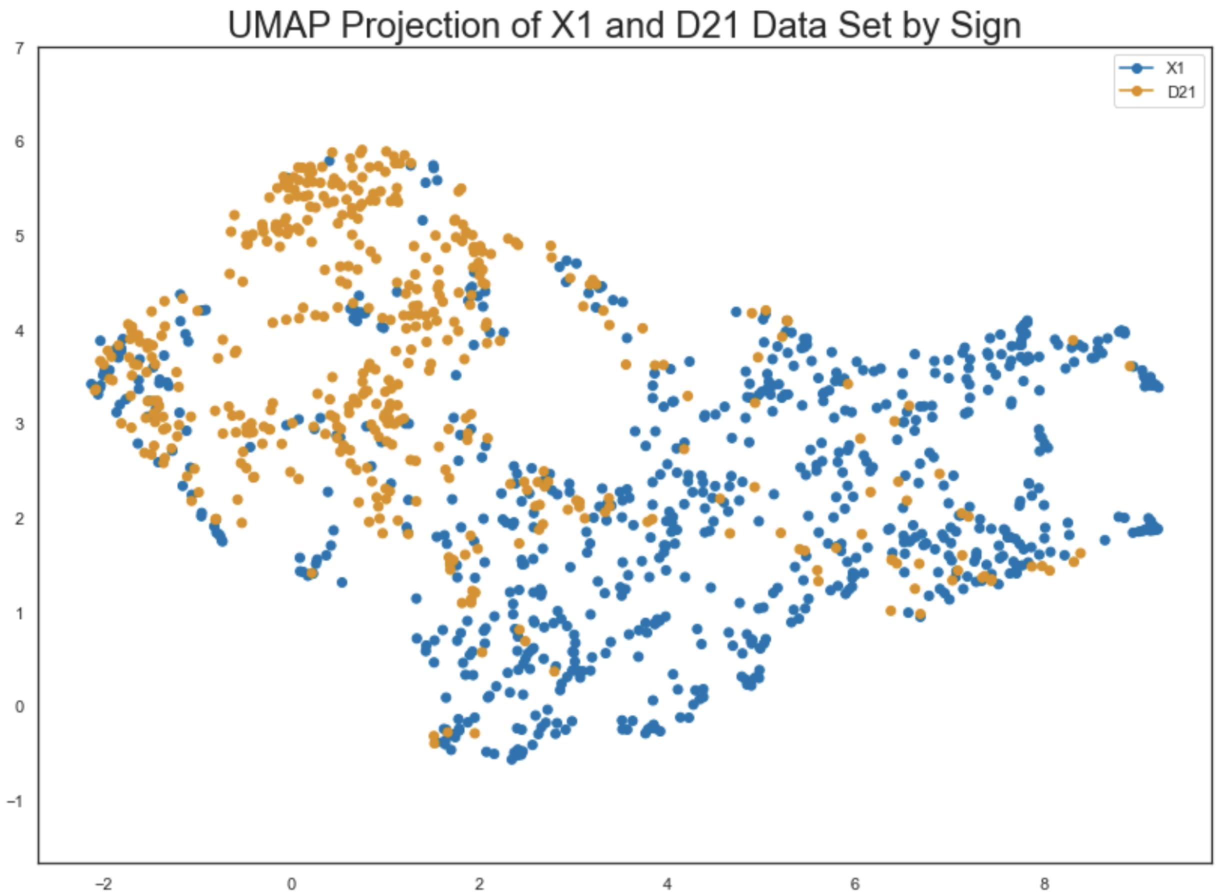


Figure 9: A UMAP plot of every X1 and D21 sign from the data set. X1 signs are in blue and D21 signs are in orange.

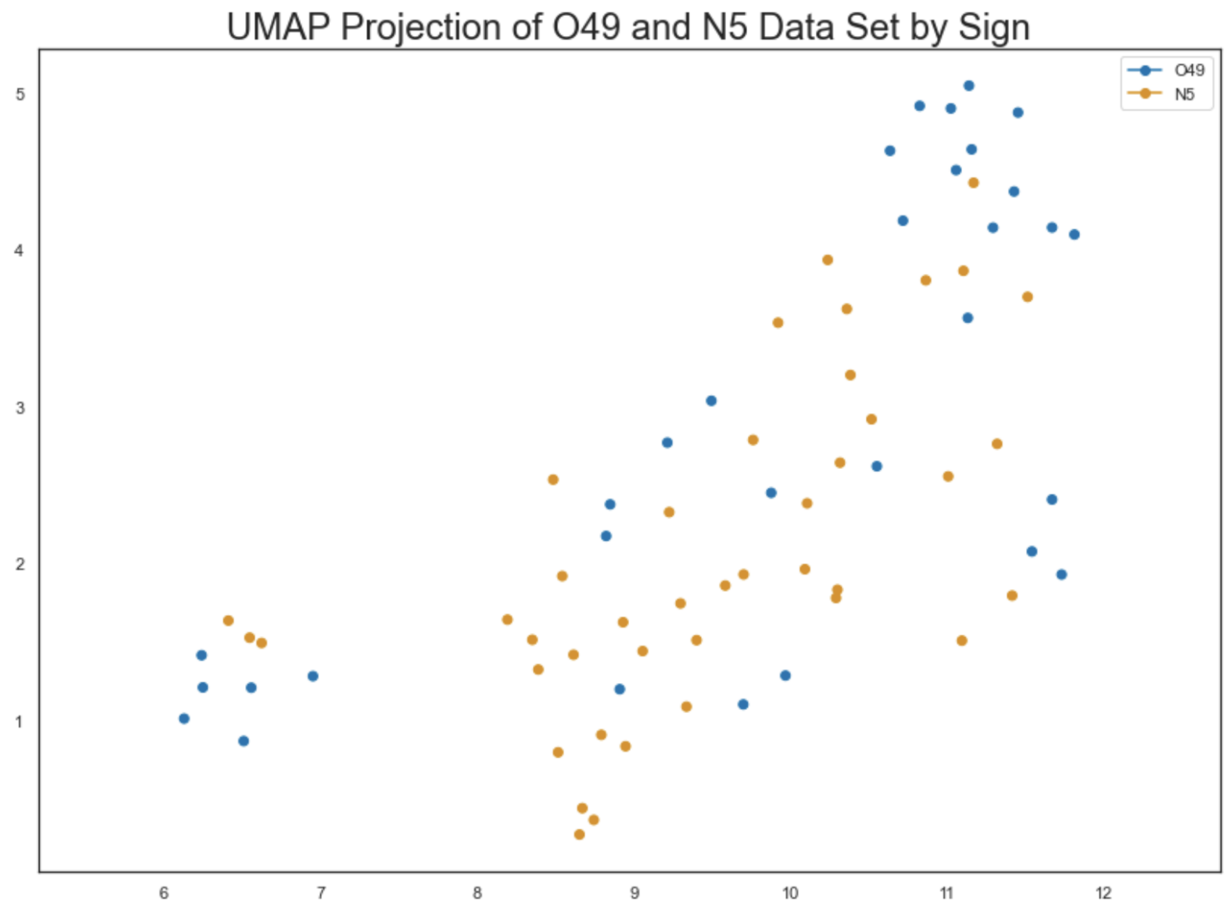


Figure 10: A UMAP plot of every O49 and N5 sign from the data set. O49 signs are in blue and N5 signs are in orange.

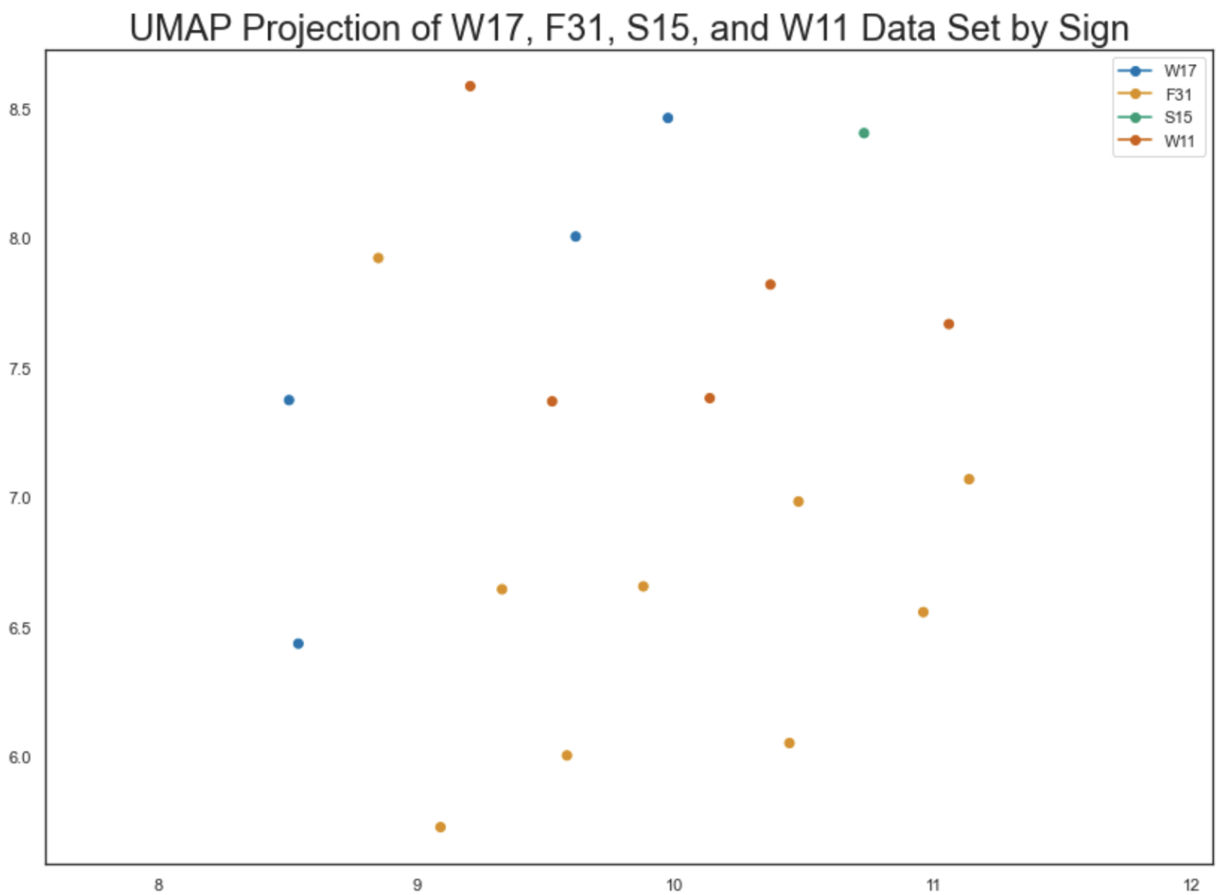


Figure 11: A UMAP plot of every W17, F31, S15, and W11 sign from the data set. W17 signs are in blue, F31 signs are in orange, S15 signs are in green, and W11 signs are in red.

Large A1 Small A1

Figure 12: A typical example of a large A1 sign (left) and a small A1 sign (right). The large A1 comes from Papyrus Prisse and the small A1 comes from Eloquent Peasant B1.

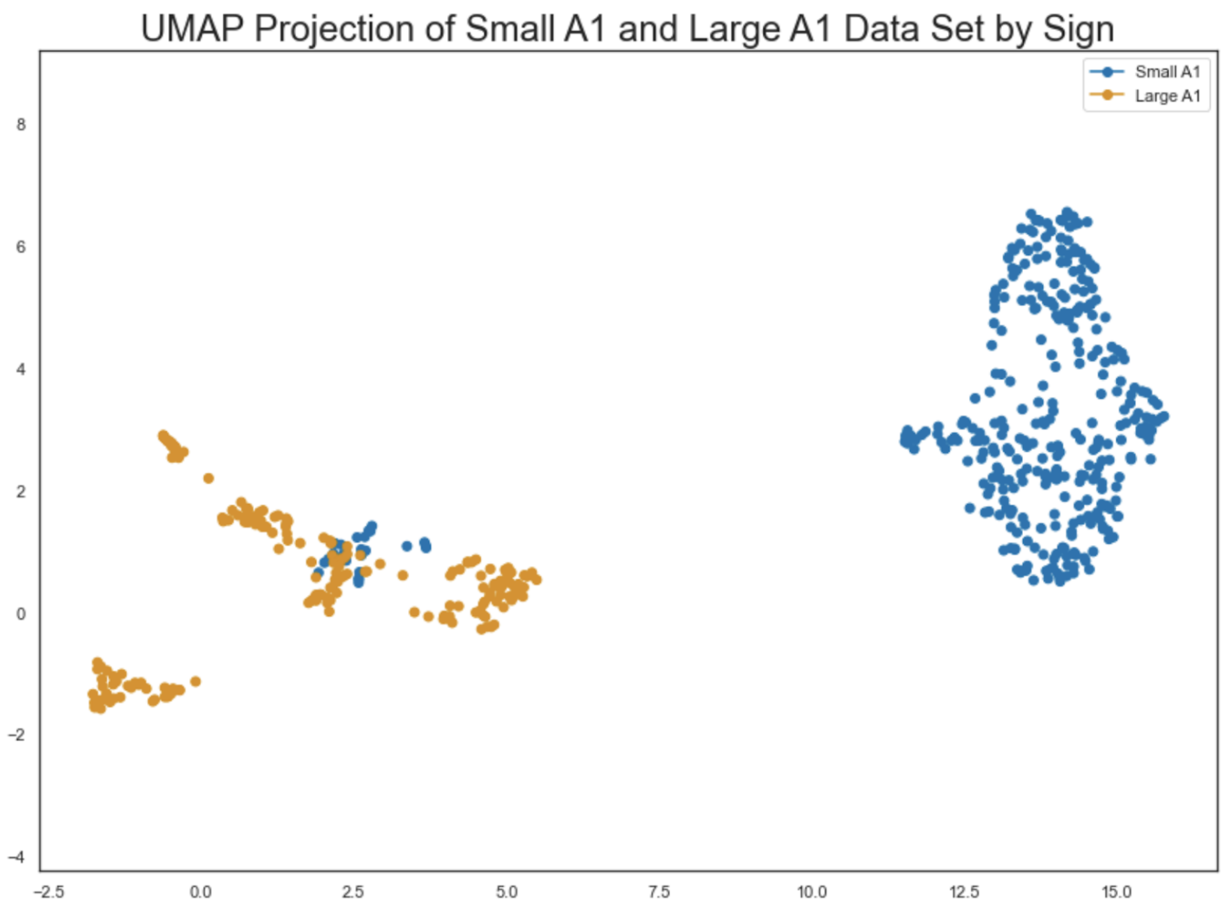


Figure 13: A UMAP plot of every small A1 and large A1 sign from the data set. Small A1 signs are in blue and large A1 signs are in orange.

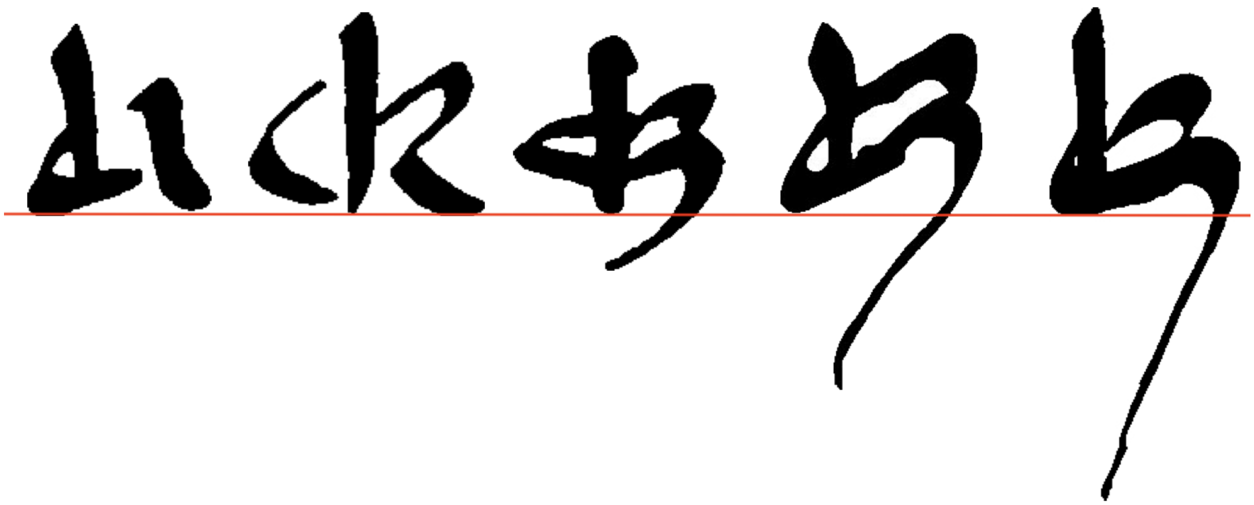


Figure 14: Four examples of large A1 signs, showing the great tail variation. The red line indicates where the tail would be cut according to the "lowest black pixel not in the tail" method. The signs come from, in order of left to right, Sinuhe B, Texte aus Hatnub, Papyrus Ebers, Eloquent Peasant B1, and Eloquent Peasant B1.

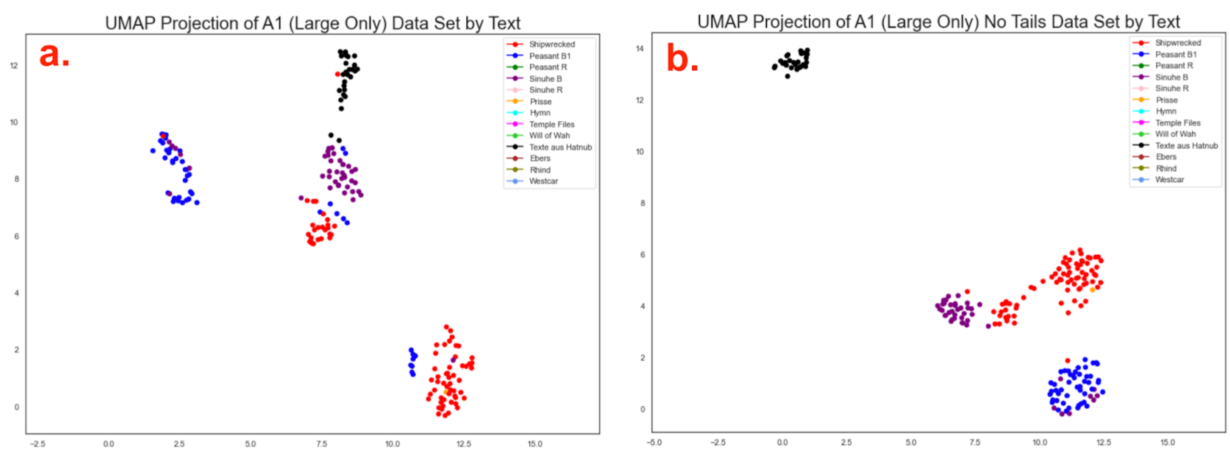


Figure 15: Two UMAP plots of every large A1 sign from the data set with (a.) and without (b.) tails, colored by text. Of the texts that appear in this plot, Shipwrecked Sailor signs are in red, Eloquent Peasant B1 signs are in blue, Sinuhe B signs are in purple, Papyrus Prisse signs are in orange, and Texte aus Hatnub signs are in black.

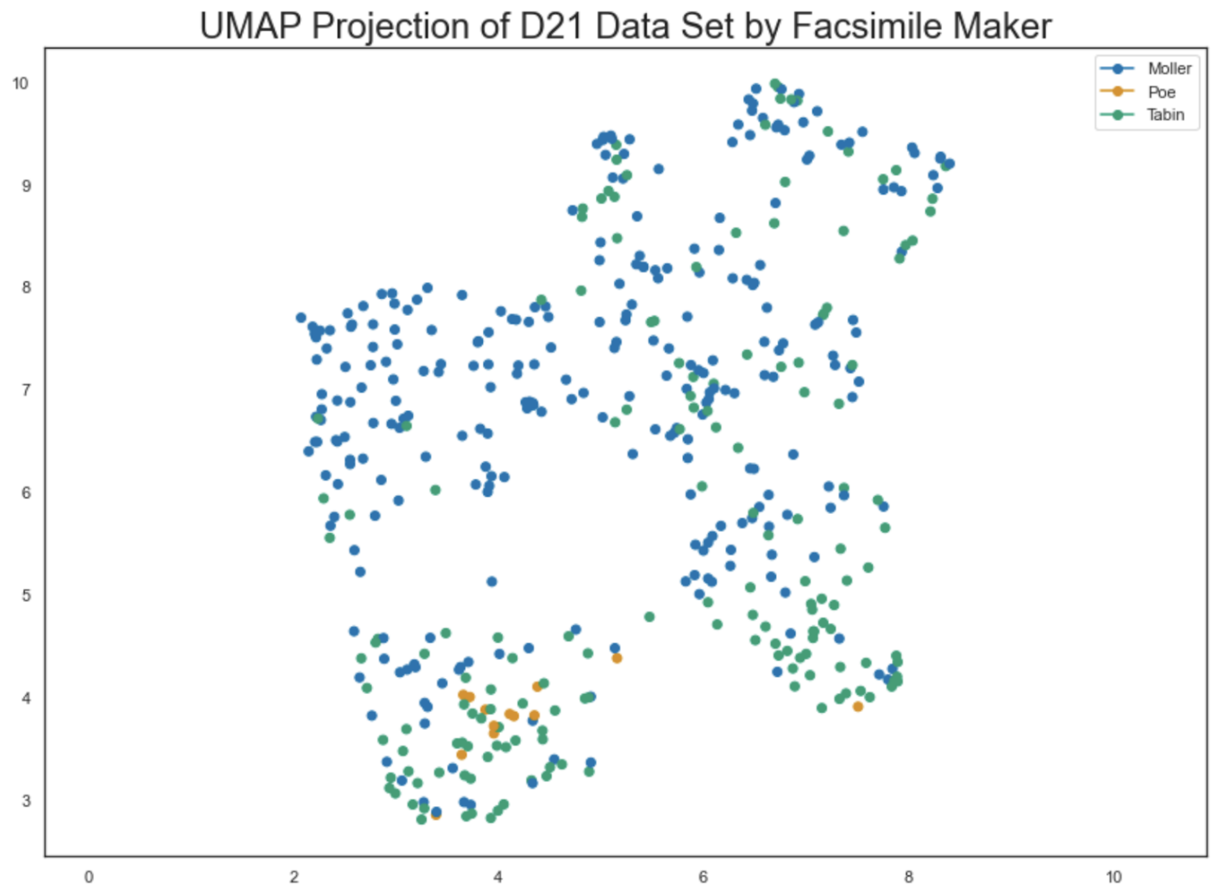


Figure 16: A UMAP plot of every D21 sign from the data set, colored by facsimile maker. Möller signs are in blue, Poe signs are in orange, and Tabin signs are in green.

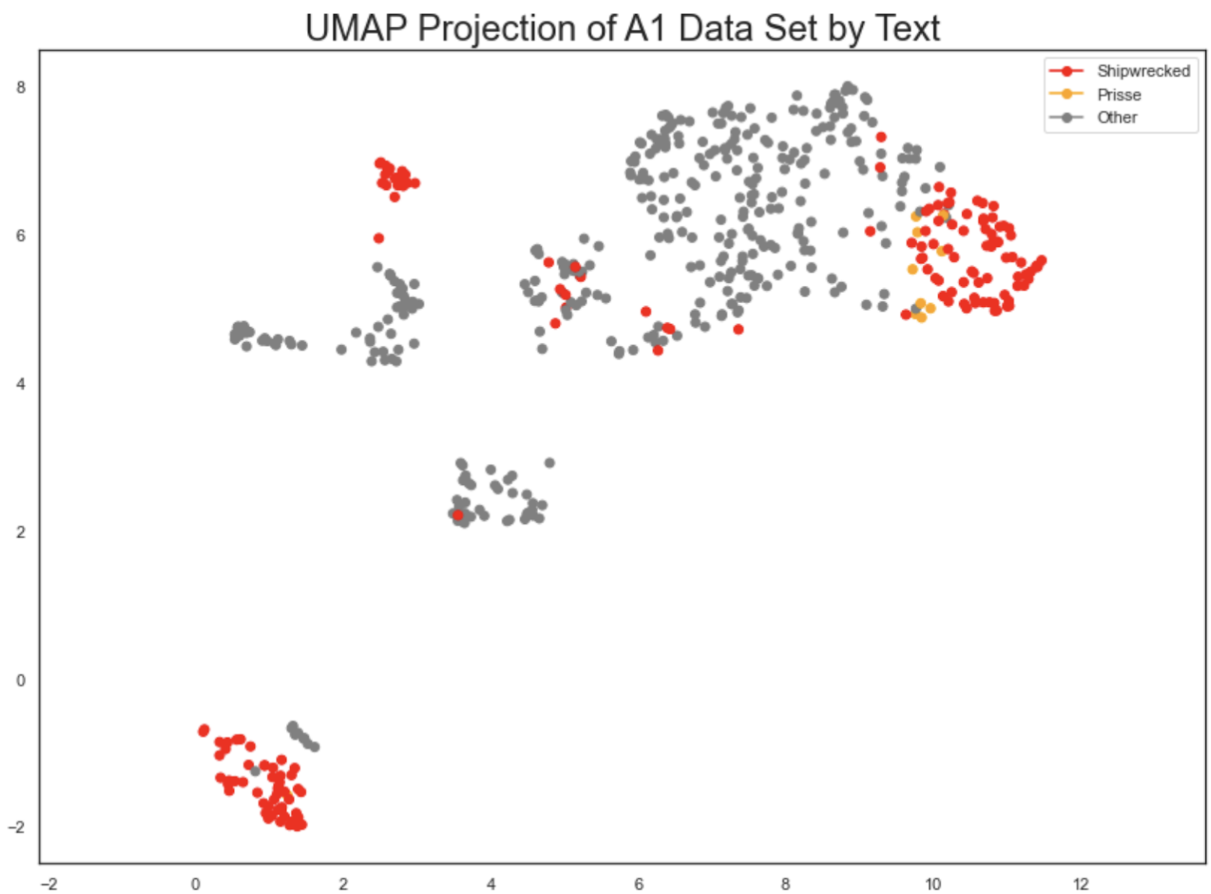


Figure 17: A UMAP plot of every A1 sign from the data set, colored by text. Shipwrecked Sailor signs are in red, Papyrus Prisse signs are in orange, and signs from all other texts are in gray.

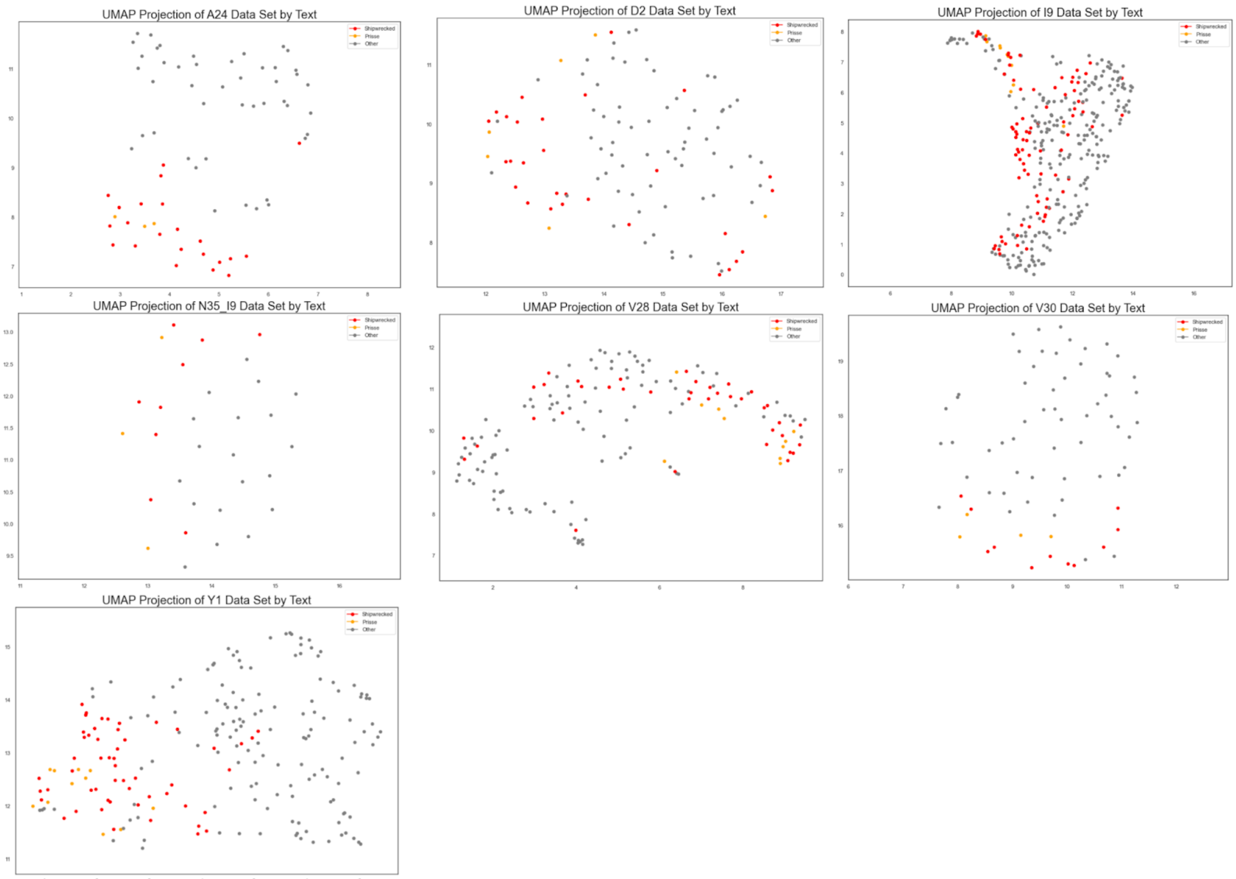


Figure 18: Seven UMAP plots of every A24, D2, I9, N35_19 ligature, V28, V30, and Y1 sign from the data set, colored by text. Shipwrecked Sailor signs are in red, Papyrus Prisse signs are in orange, and signs from all other texts are in gray.

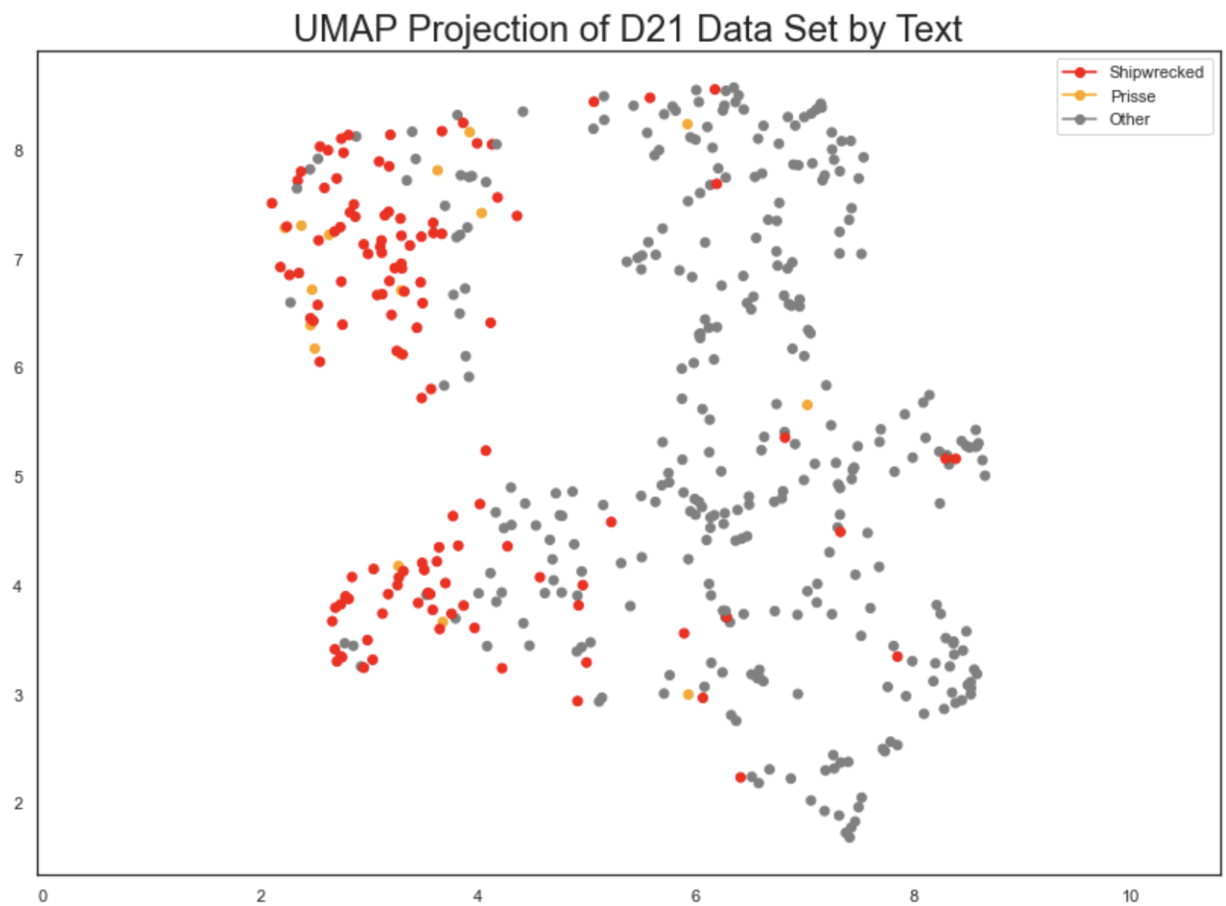


Figure 19: A UMAP plot of every D21 sign from the data set, colored by text. Shipwrecked Sailor signs are in red, Papyrus Prisse signs are in orange, and signs from all other texts are in gray.

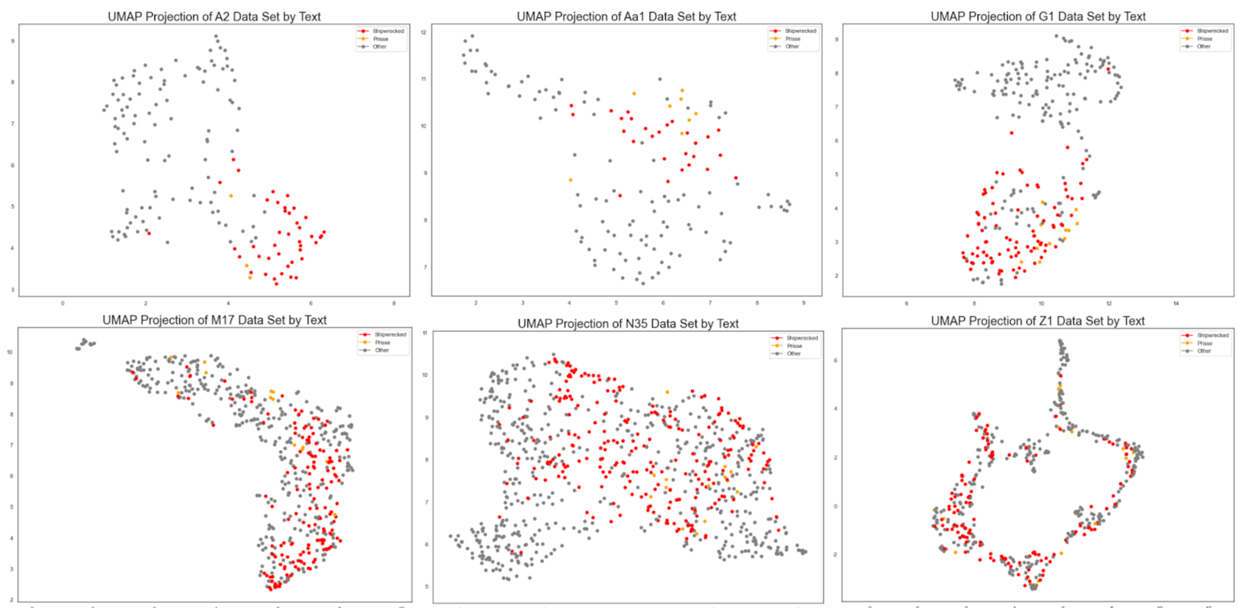


Figure 20: Six UMAP plots of every A2, Aa1, G1, M17, N35, and Z1 sign from the data set, colored by text. Shipwrecked Sailor signs are in red, Papyrus Prisse signs are in orange, and signs from all other texts are in gray.

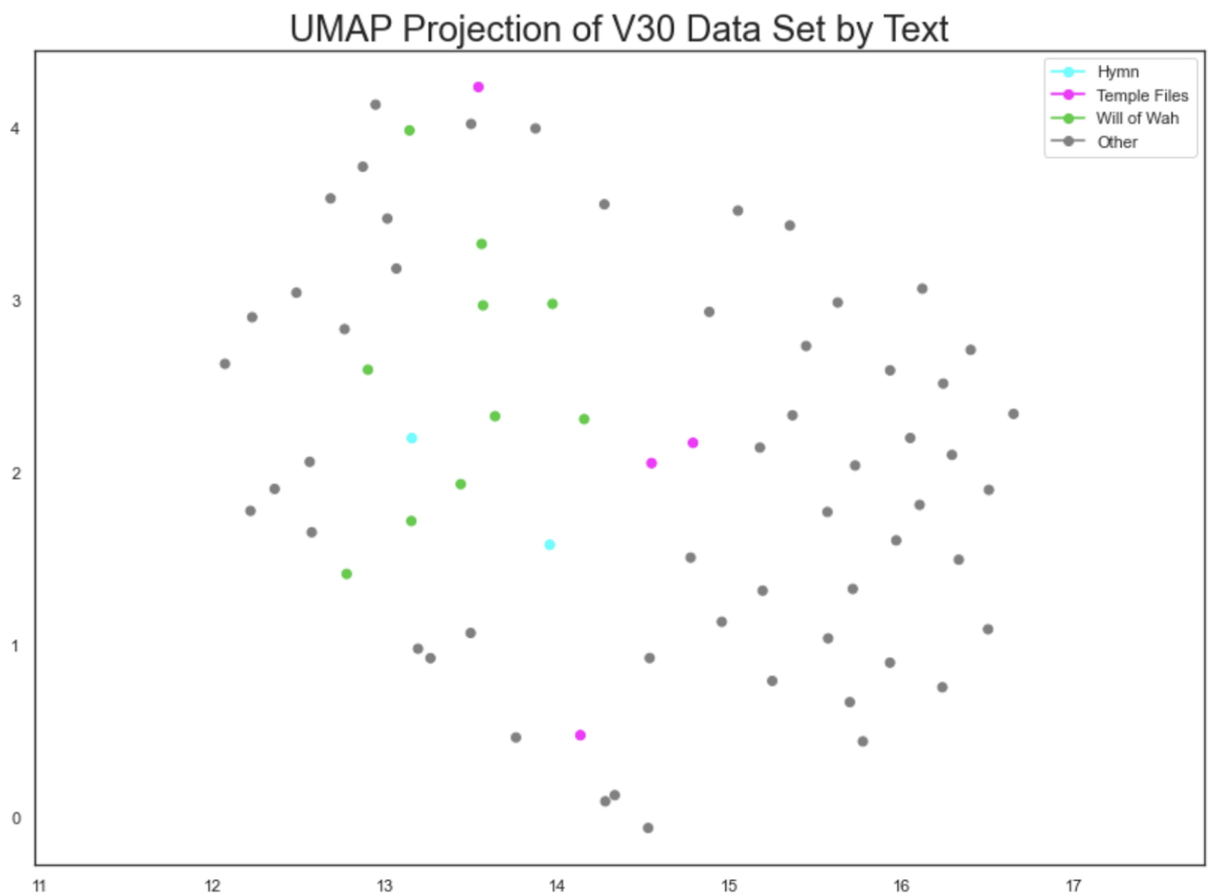


Figure 21: A UMAP plot of every V30 sign from the data set, colored by text. Hymn to Senwosret III signs are in light blue, Temple Files signs are in pink, Will of Wah signs are in light green, and signs from all other texts are in gray.

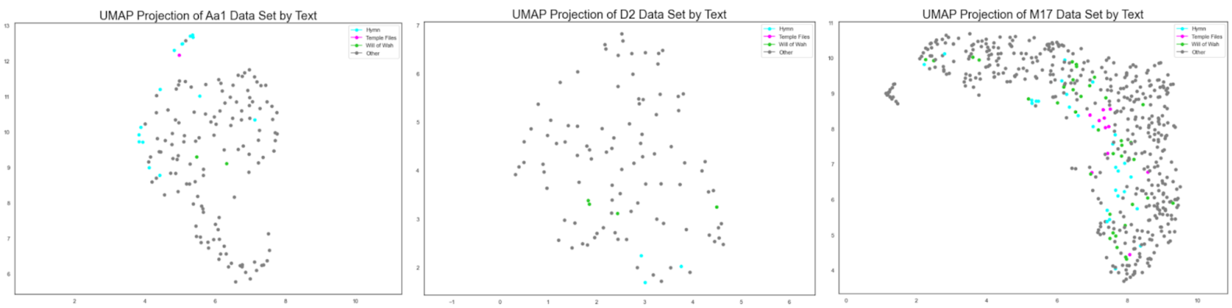


Figure 22: Three UMAP plots of every Aa1, D2, and M17 sign from the data set, colored by text. Hymn to Senwosret III signs are in light blue, Temple Files signs are in pink, Will of Wah signs are in light green, and signs from all other texts are in gray.

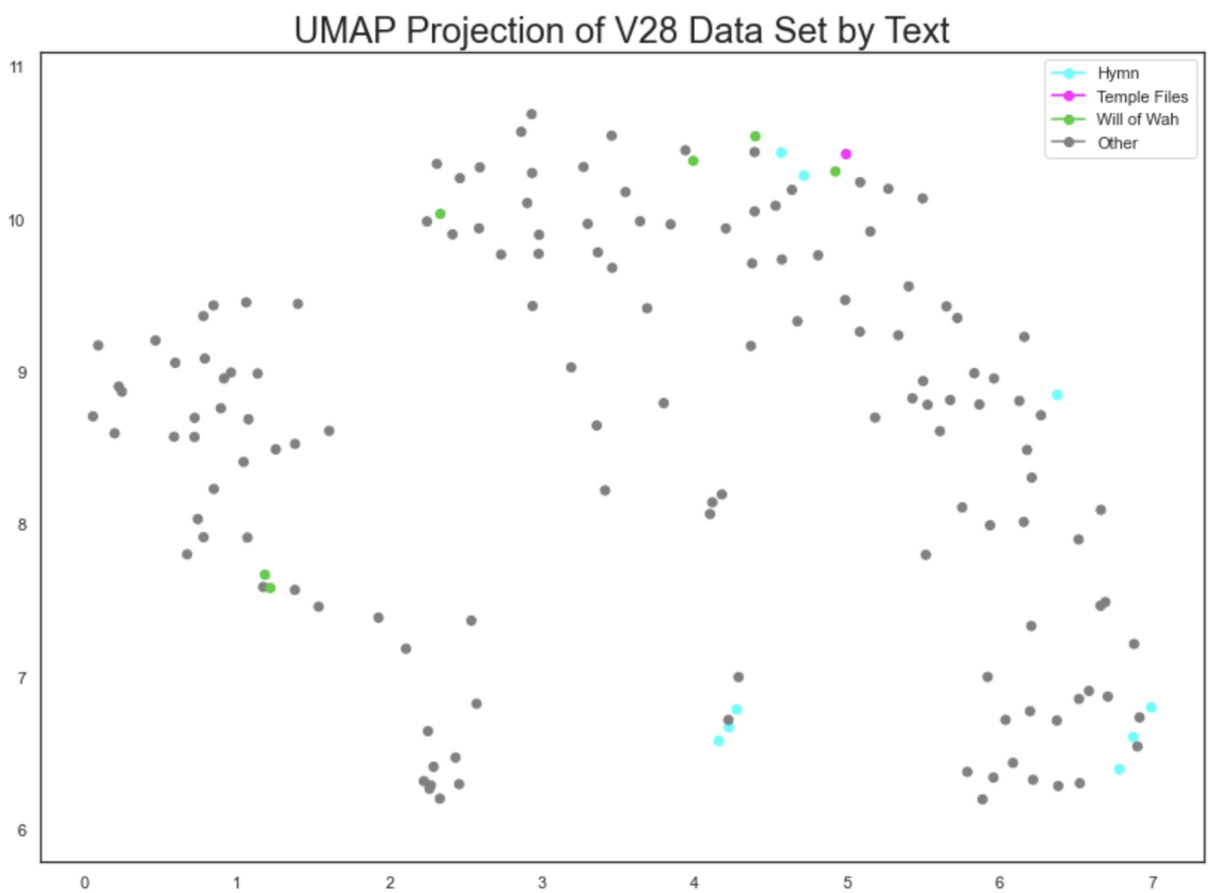


Figure 23: A UMAP plot of every V28 sign from the data set, colored by text. Hymn to Senwosret III signs are in light blue, Temple Files signs are in pink, Will of Wah signs are in light green, and signs from all other texts are in gray.

Figure 24: Eight UMAP plots of every A1, D46, I9, N35, X1, Y1, Z1, and Z2 sign from the data set, colored by text. Hymn to Senwosret III signs are in light blue, Temple Files signs are in pink, Will of Wah signs are in light green, and signs from all other texts are in gray.

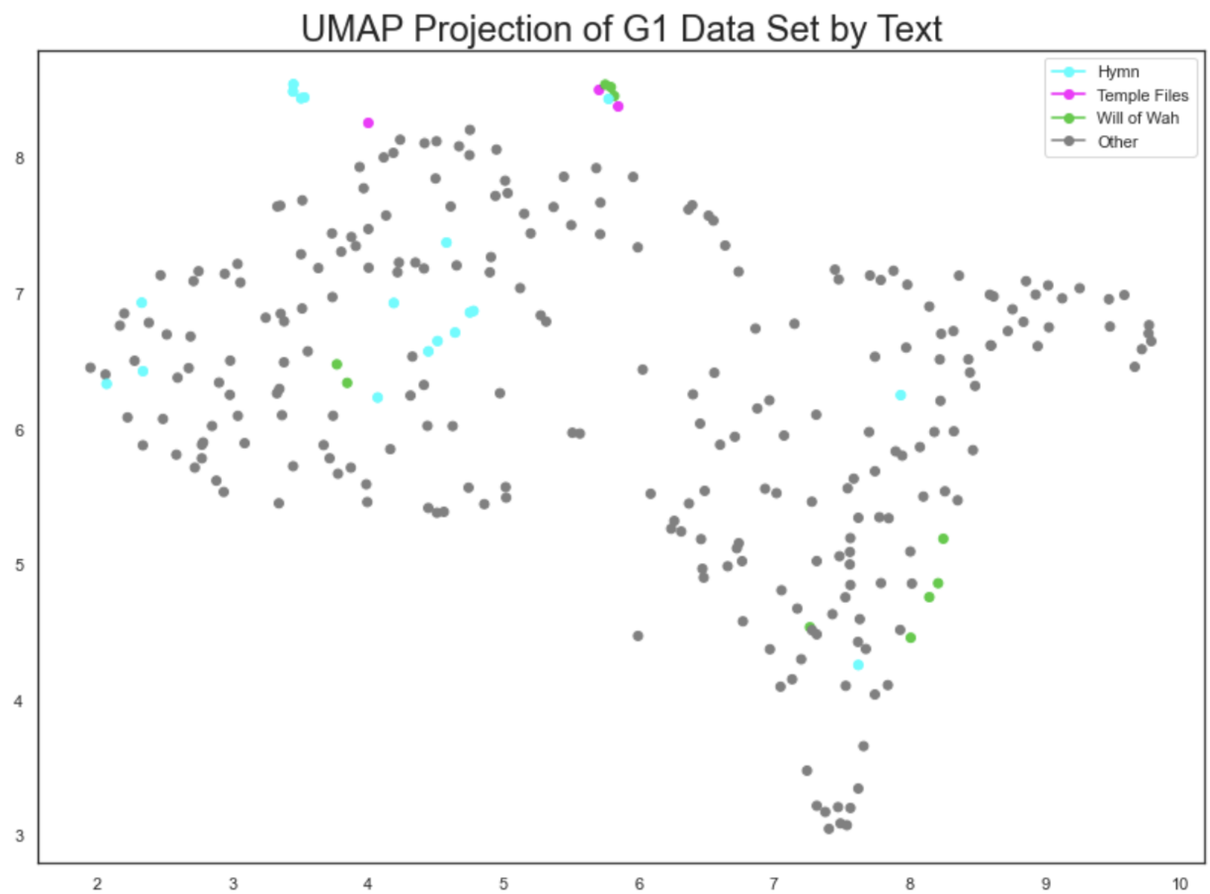


Figure 25: A UMAP plot of every G1 sign from the data set, colored by text. Hymn to Senwosret III signs are in light blue, Temple Files signs are in pink, Will of Wah signs are in light green, and signs from all other texts are in gray.

Figure 26: A typical example of a G1 sign (left) and an example of an atypical G1 sign (right). Both signs are from the Hymn to Senwosret III.

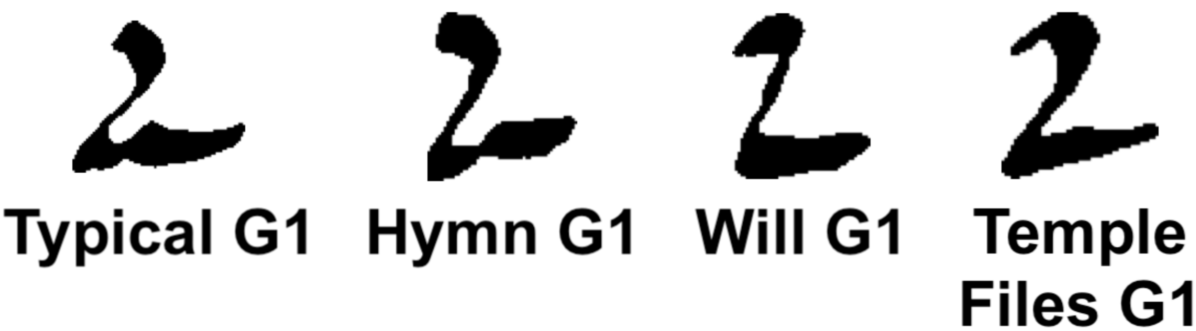


Figure 27: A typical example of a G1 sign (left) and three examples of atypical z-shaped G1 signs (right three). The first two signs are from the Hymn to Senwosret III, the second to last is from the Will of Wah, and the last is from the Temple Files.

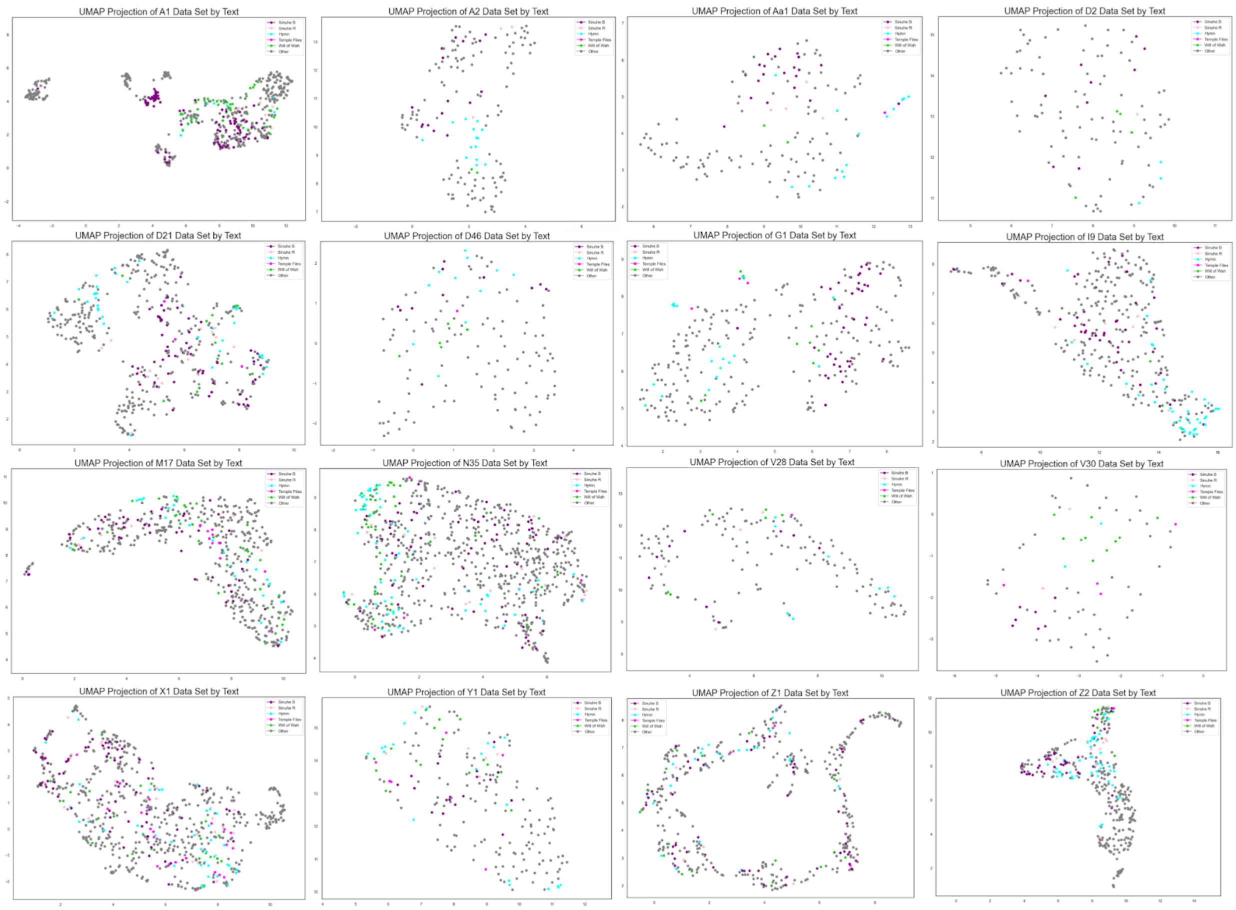


Figure 28: Sixteen UMAP plots of every A1, A2, Aa1, D2, D21, D46, G1, I9, M17, N35, V28, V30, X1, Y1, Z1, and Z2 sign from the data set, colored by text. Sinuhe B signs are in purple, Sinuhe R signs are in light pink, Hymn to Senwosret III signs are in light blue, Temple Files signs are in pink, Will of Wah signs are in light green, and signs from all other texts are in gray.

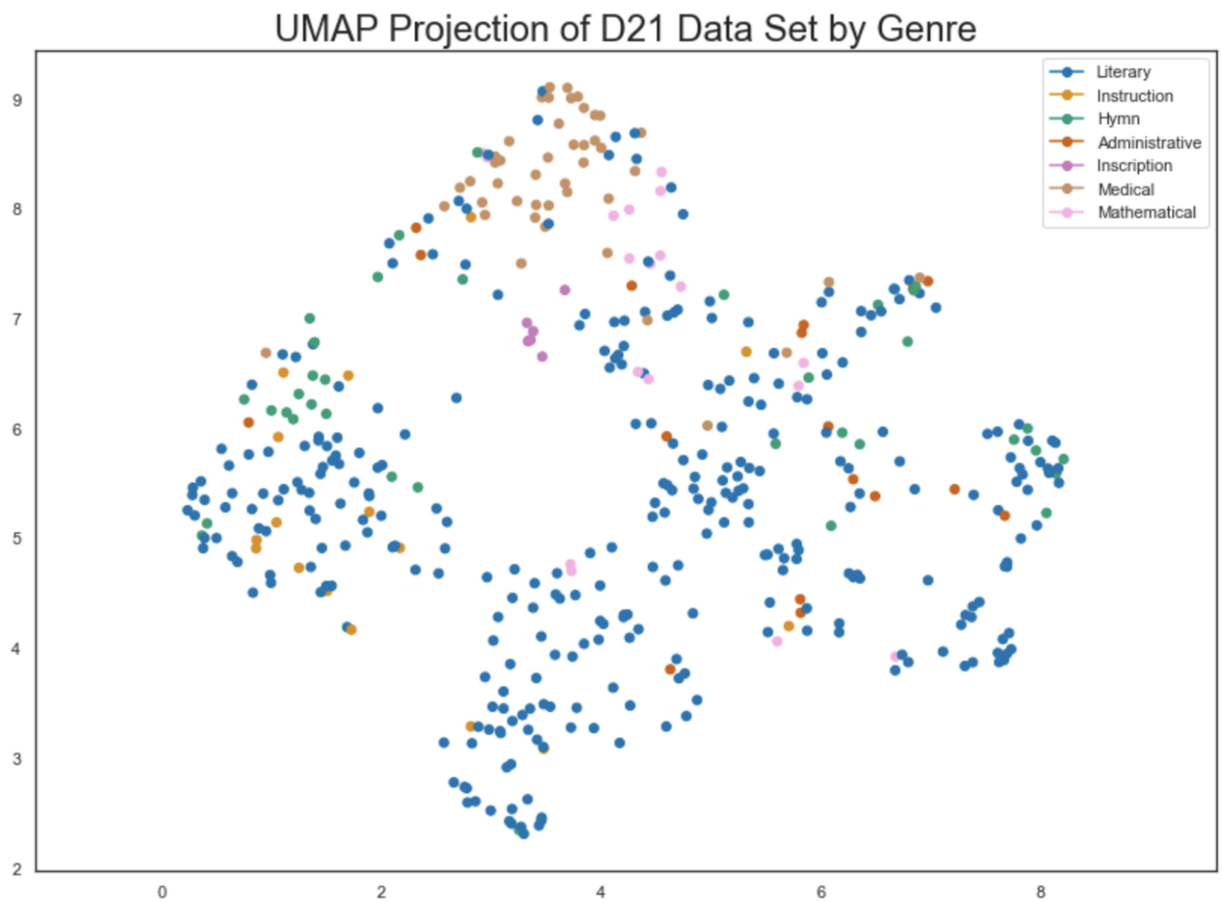


Figure 29: A UMAP plot of every D21 sign from the data set, colored by genre. Literary signs are in blue, instruction signs are in orange, hymn signs are in green, administrative signs are in red, inscription signs are in purple, medical signs are in brown, and mathematical signs are in pink.

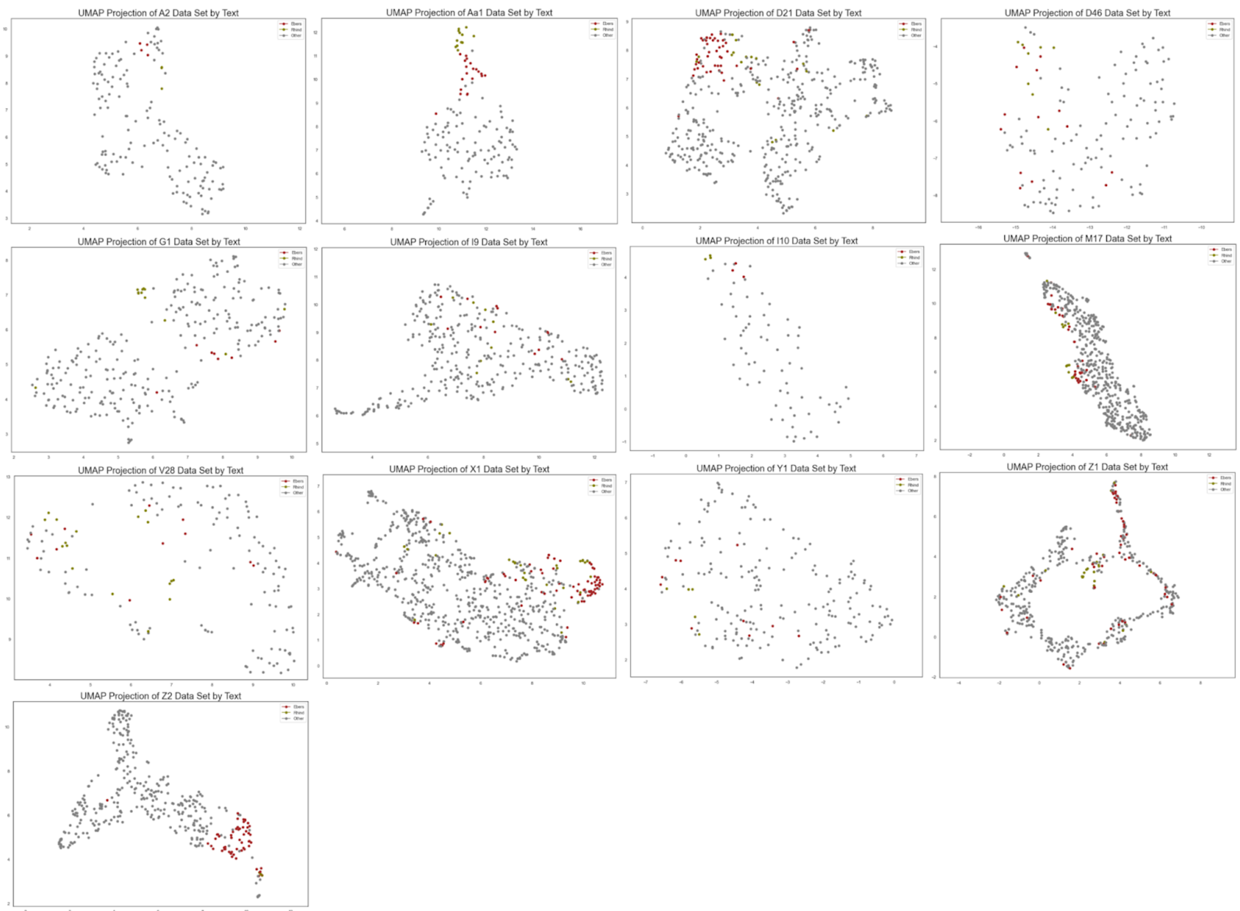


Figure 30: Thirteen UMAP plots of every A2, Aa1, D21, D46, G1, I9, I10, M17, V28, X1, Y1, Z1, and Z2 sign from the data set, colored by text. Papyrus Ebers signs are in dark red, Rhind Papyrus signs are in yellow, and signs from all other texts are in gray.

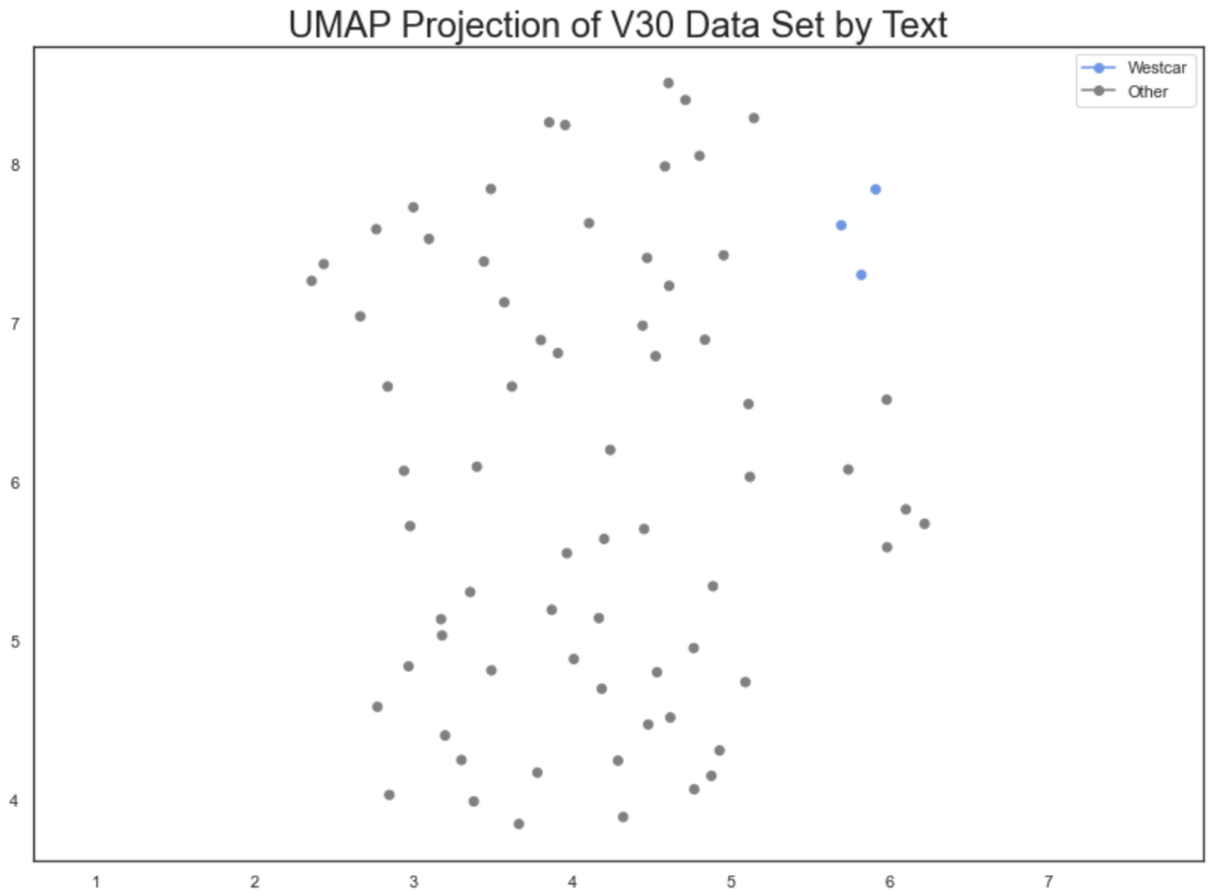


Figure 31: A UMAP plot of every V30 sign from the data set, colored by text. Papyrus Westcar signs are in cornflower blue and signs from all other texts are in gray.

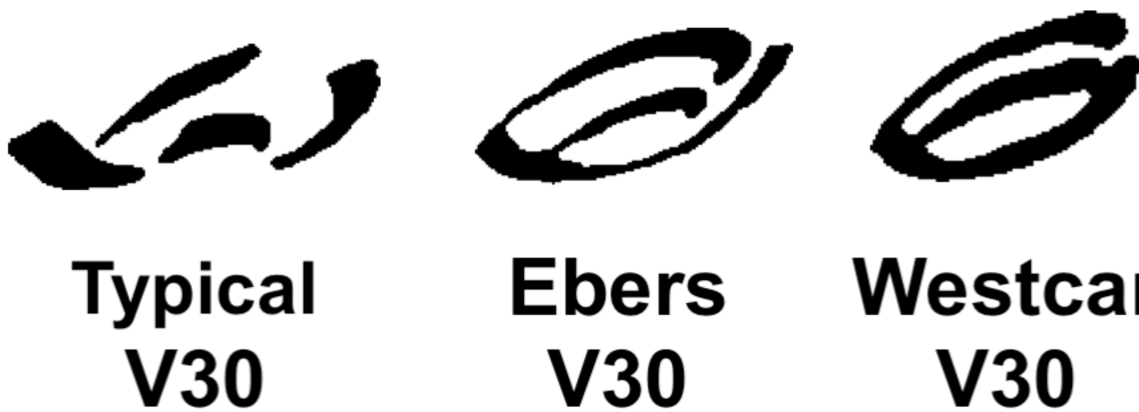


Figure 32: A typical example of a V30 sign (left), an example of an Ebers V30 sign (middle), and an example of a Westcar V30 (right).

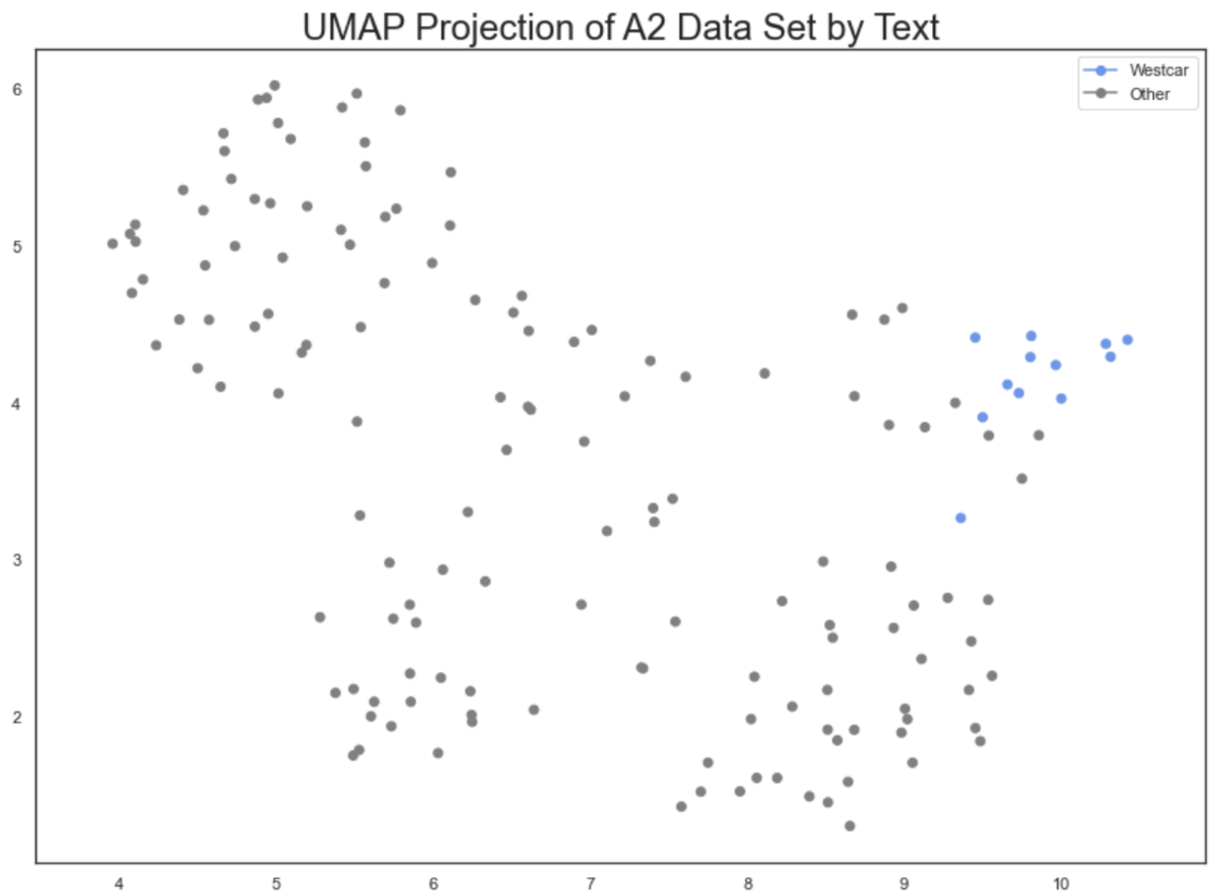


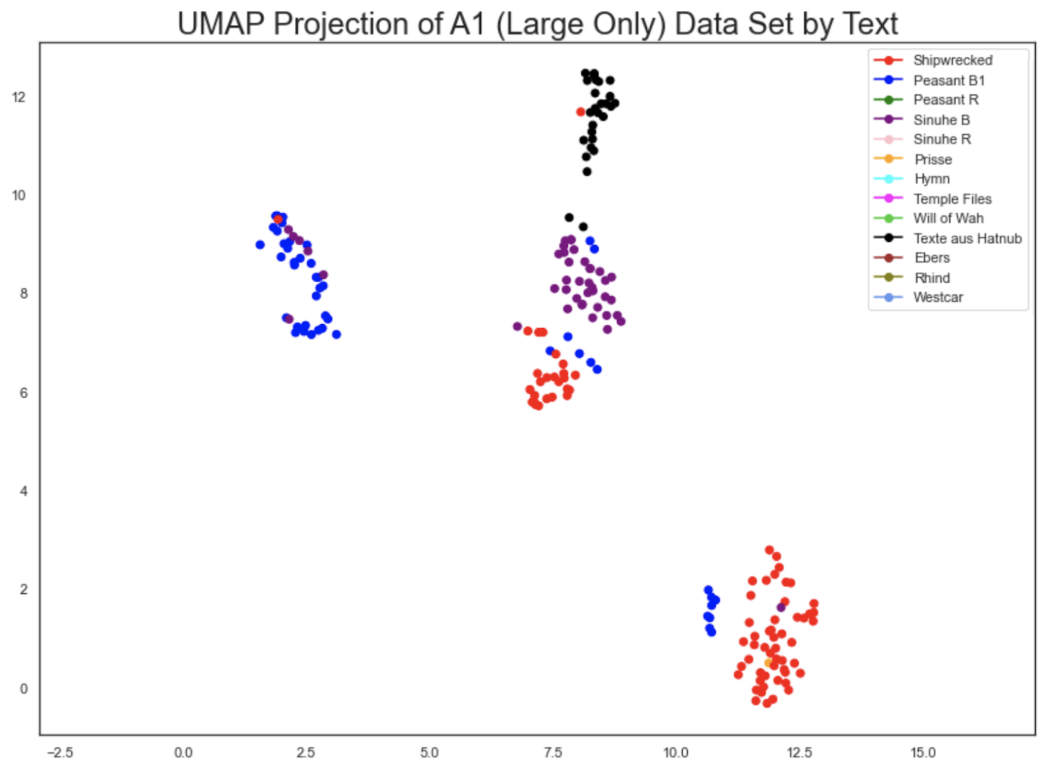
Figure 33: A UMAP plot of every A2 sign from the data set, colored by text. Papyrus Westcar signs are in cornflower blue and signs from all other texts are in gray.

Figure 34: Four typical examples of A2 signs (left four) and an example of a Westcar A2 sign (right).

Appendix 1: Expanded Figures

As mentioned in the Figures section, this part of the appendix contains individual graphs for the figures with many parts, to ensure readability. These multi-part figures are Figure 15 (pg. 113), Figure 18 (pg. 114-117), Figure 20 (pg. 118-120), Figure 22 (pg. 121-122), Figure 24 (pg. 123-126), Figure 28 (pg. 127-134), and Figure 30 (pg. 135-141). See the corresponding figures in the above section for a description of the graphs.

Figure 15


UMAP Projection of A1 (Large Only) Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
12
10
8
6
4
2
0
−2.5
0.0
2.5
5.0
7.5
10.0
12.5
15.0

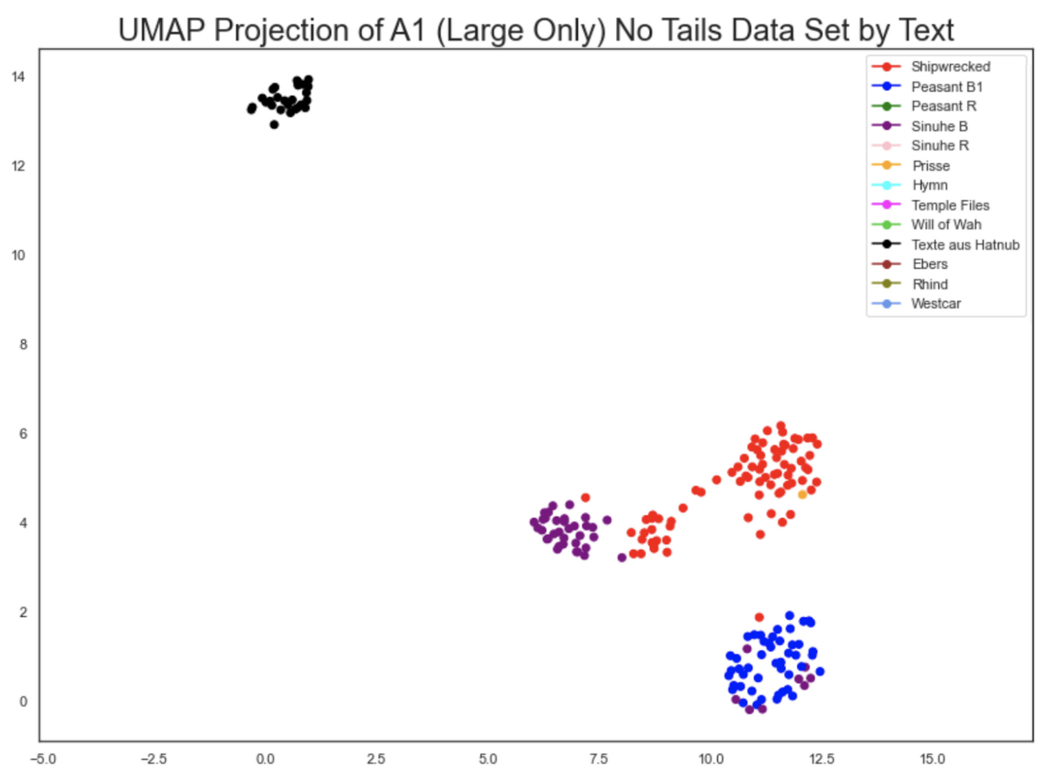

UMAP Projection of A1 (Large Only) No Tails Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
14
12
10
8
6
4
2
0
−5.0
−2.5
0.0
2.5
5.0
7.5
10.0
12.5
15.0

Figure 18

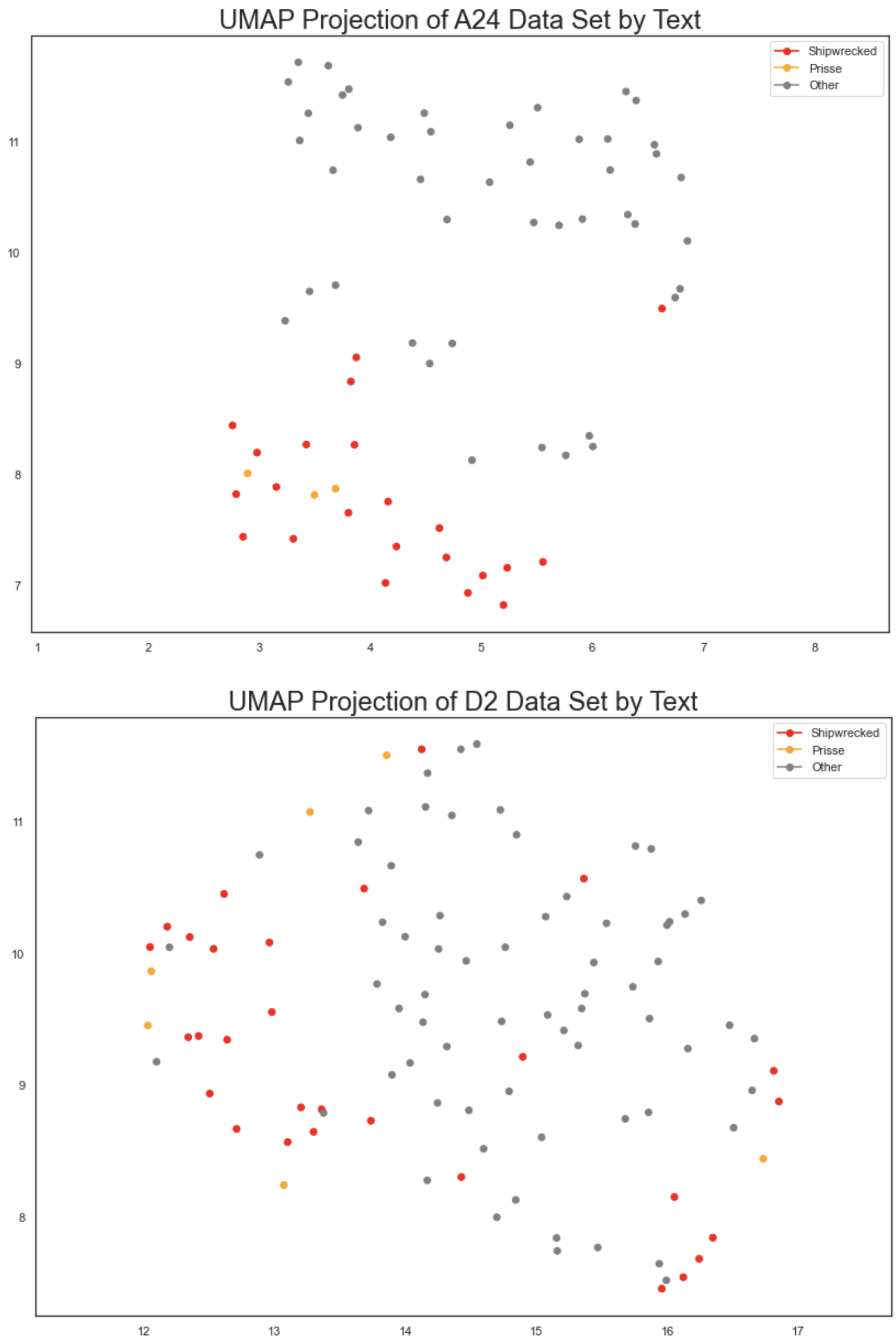
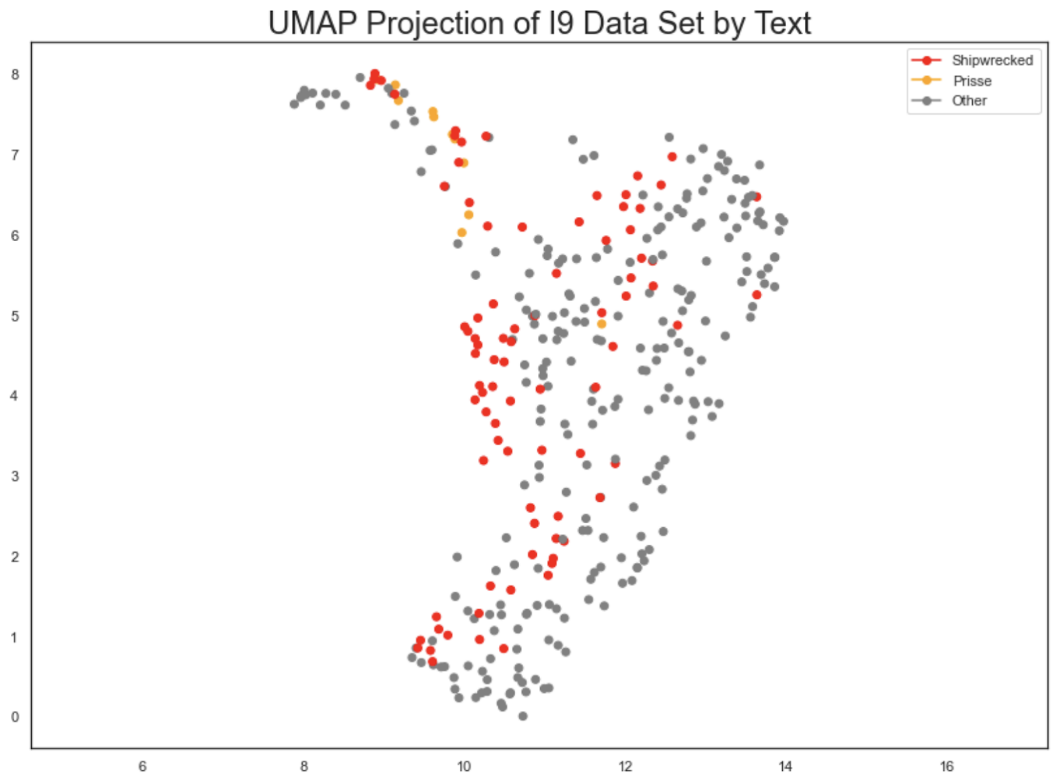

UMAP Projection of A24 Data Set by Text
Shipwrecked
Prisse
Other
11
10
9
8
7
1
2
3
4
5
6
7
8
UMAP Projection of D2 Data Set by Text
Shipwrecked
Prisse
Other
11
10
9
8
12
13
14
15
16
17

Figure 18


UMAP Projection of I9 Data Set by Text
Shipwrecked
Prisse
Other
8
7
6
5
4
3
2
1
0
6
8
10
12
14
16

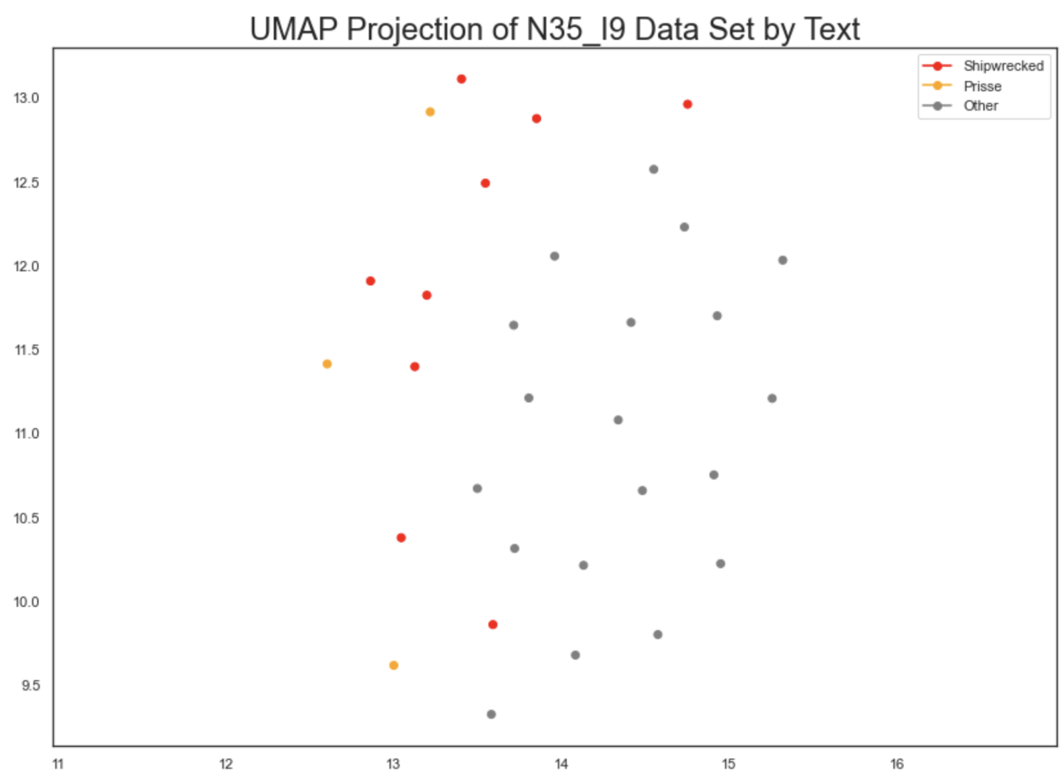
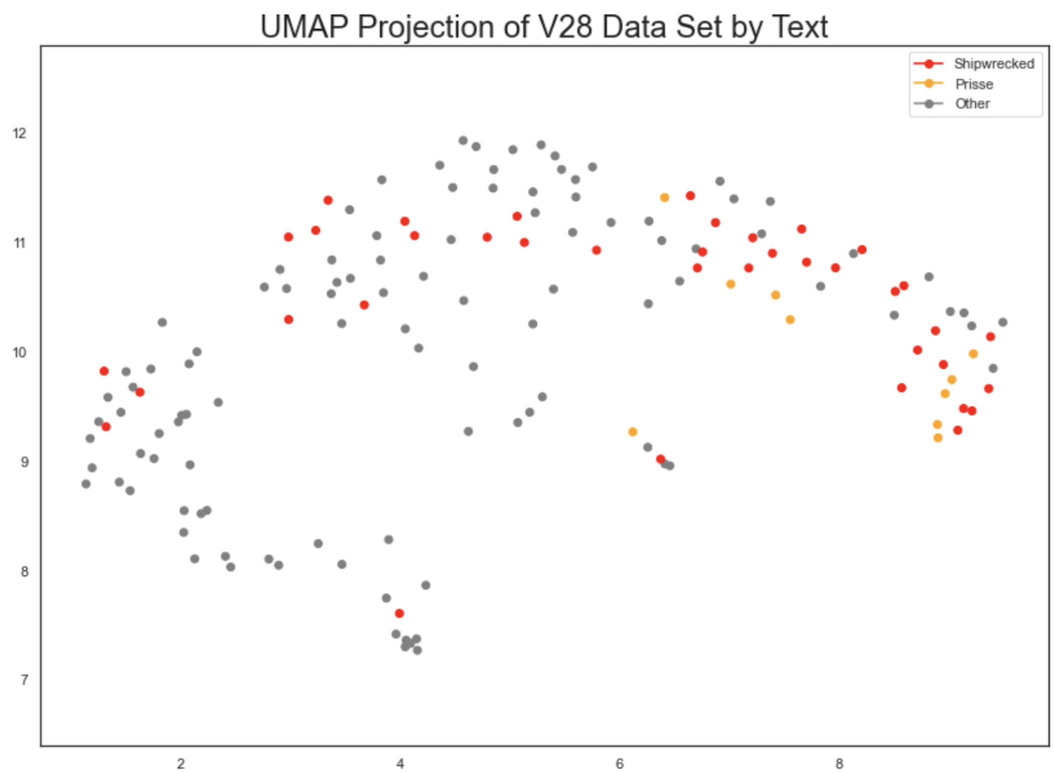

UMAP Projection of N35_I9 Data Set by Text
Shipwrecked
Prisse
Other
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
11
12
13
14
15
16

Figure 18


UMAP Projection of V28 Data Set by Text
Shipwrecked
Prisse
Other
12
11
10
9
8
7
2
4
6
8

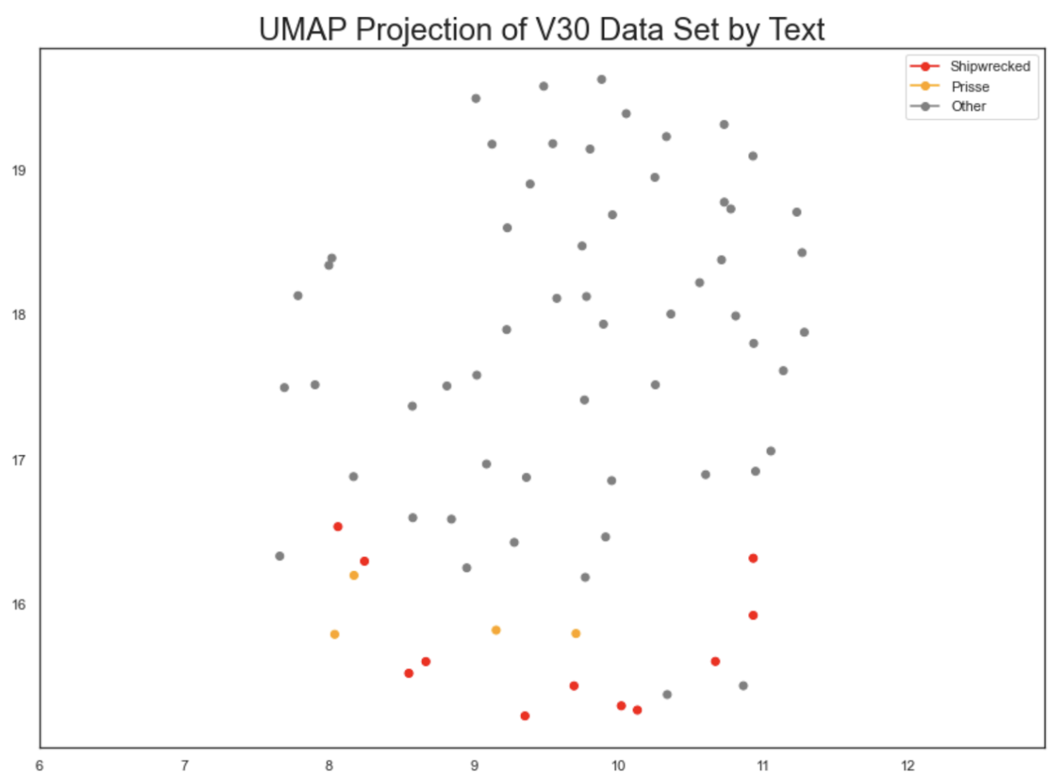

UMAP Projection of V30 Data Set by Text
Shipwrecked
Prisse
Other
19
18
17
16
6
7
8
9
10
11
12

Figure 18

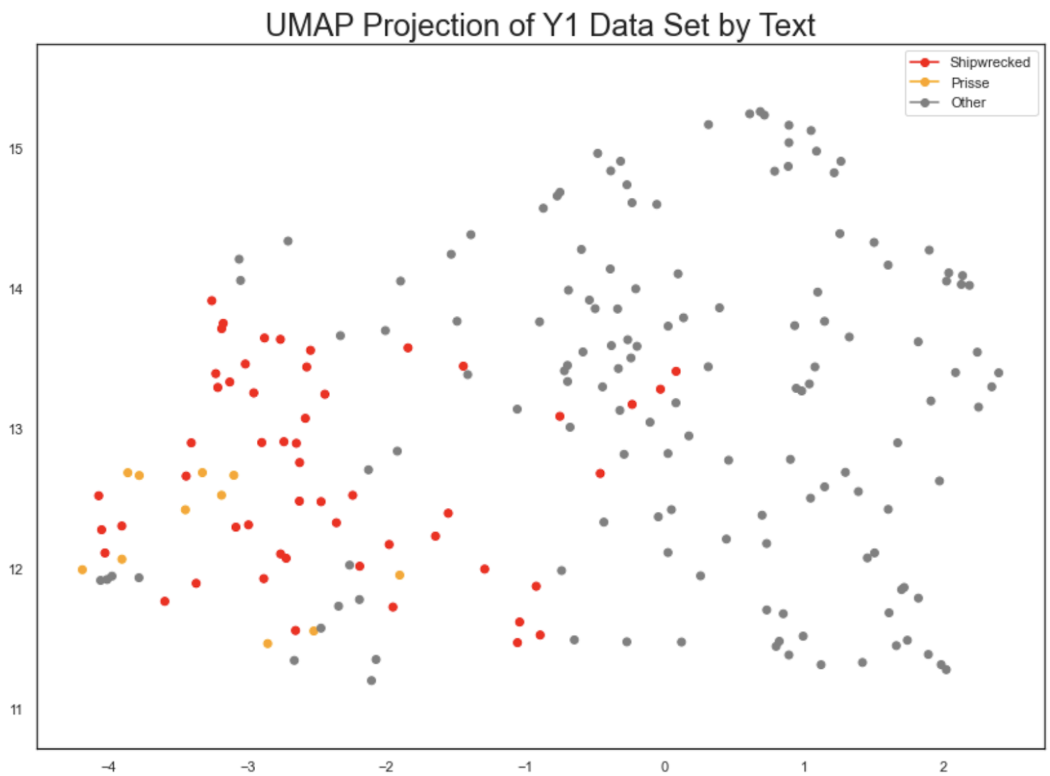
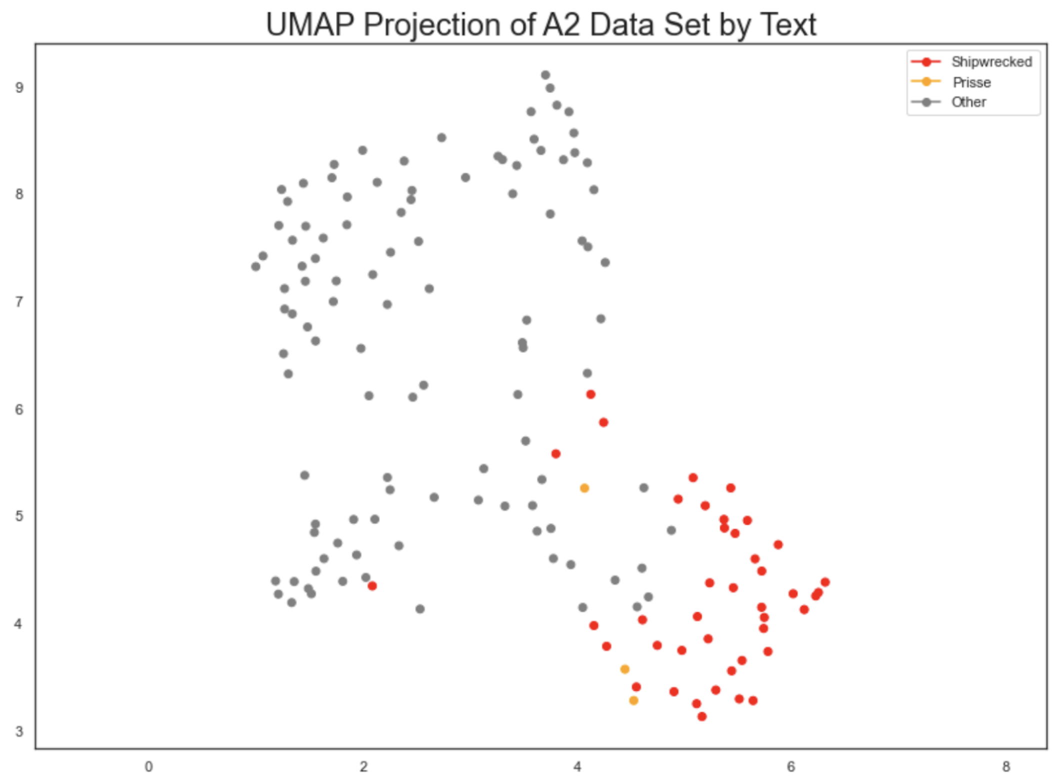

UMAP Projection of Y1 Data Set by Text
Shipwrecked
Prisse
Other
15
14
13
12
11
−4
−3
−2
−1
0
1
2

Figure 20


UMAP Projection of A2 Data Set by Text
Shipwrecked
Prisse
Other
9
8
7
6
5
4
3
0
2
4
6
8

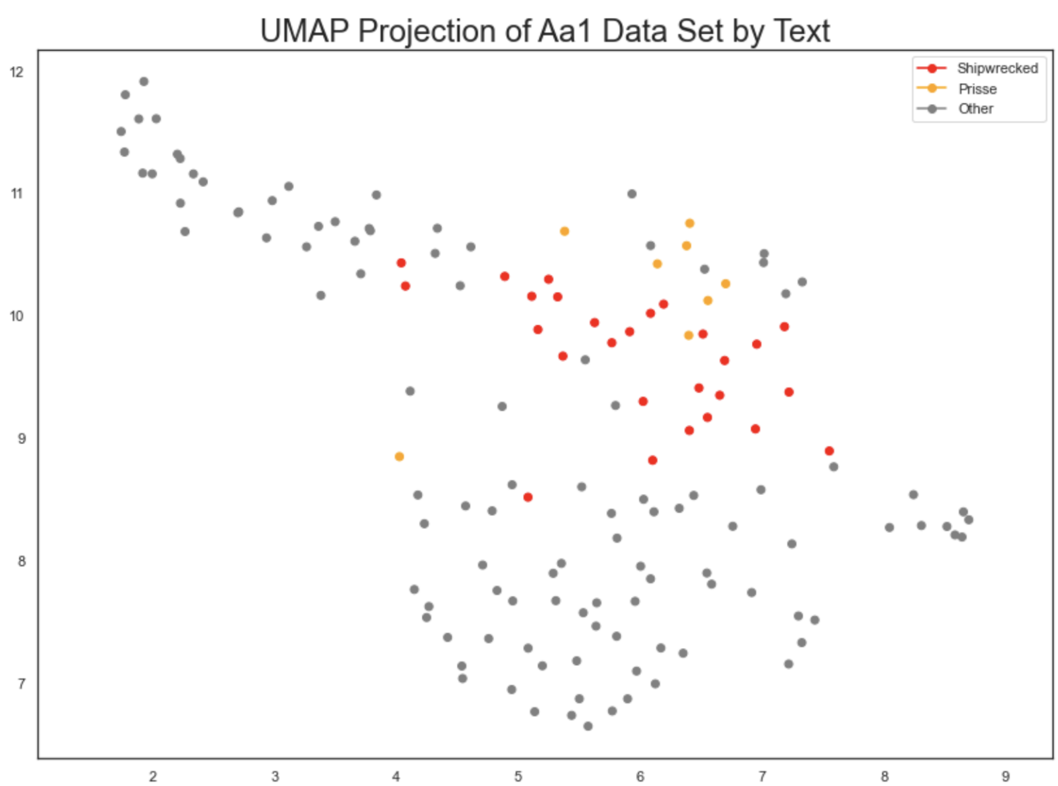
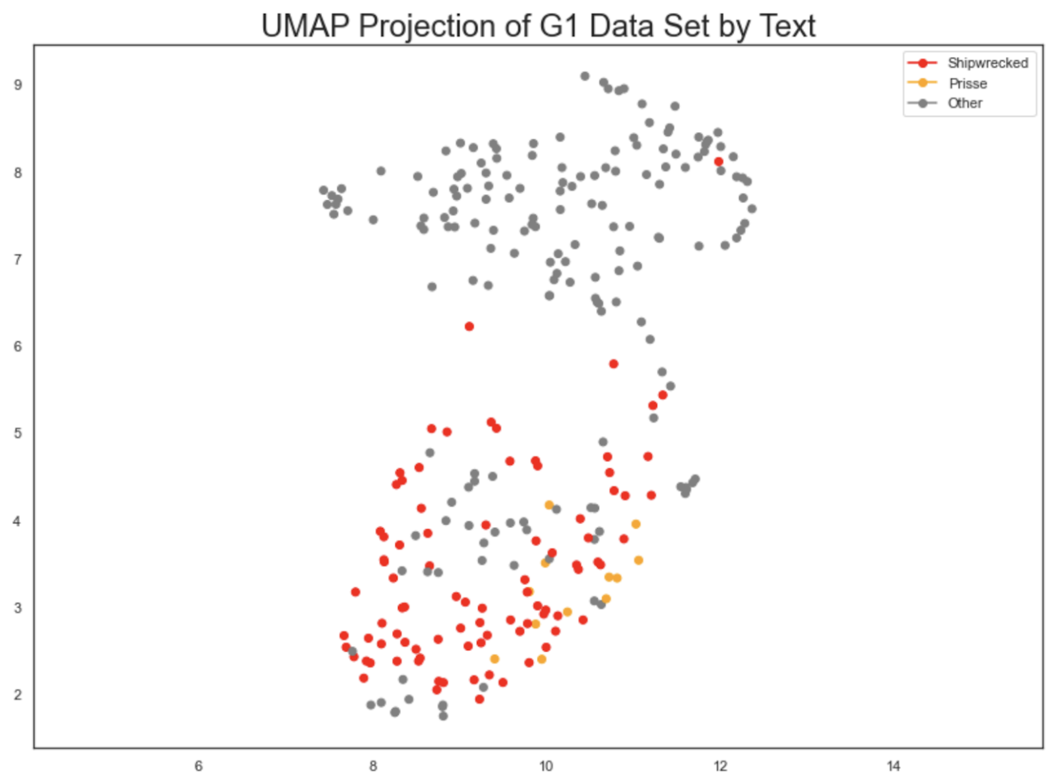

UMAP Projection of Aa1 Data Set by Text
Shipwrecked
Prisse
Other
12
11
10
9
8
7
2
3
4
5
6
7
8
9

Figure 20


UMAP Projection of G1 Data Set by Text
Shipwrecked
Prisse
Other
9
8
7
6
5
4
3
2
6
8
10
12
14

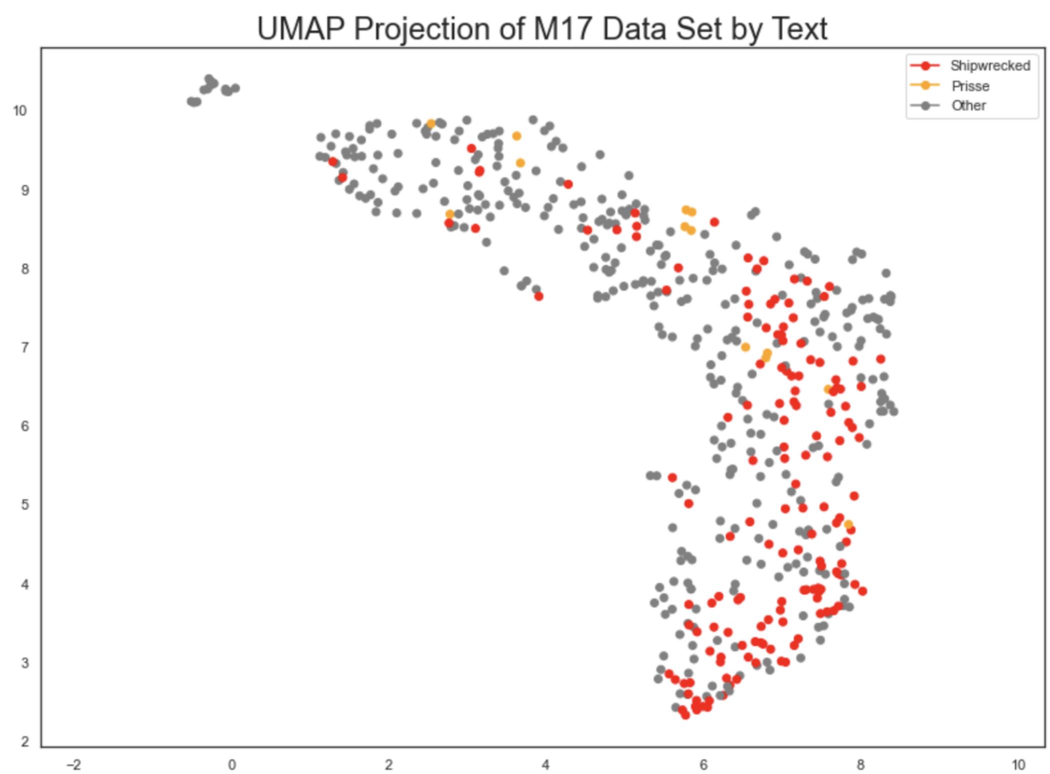
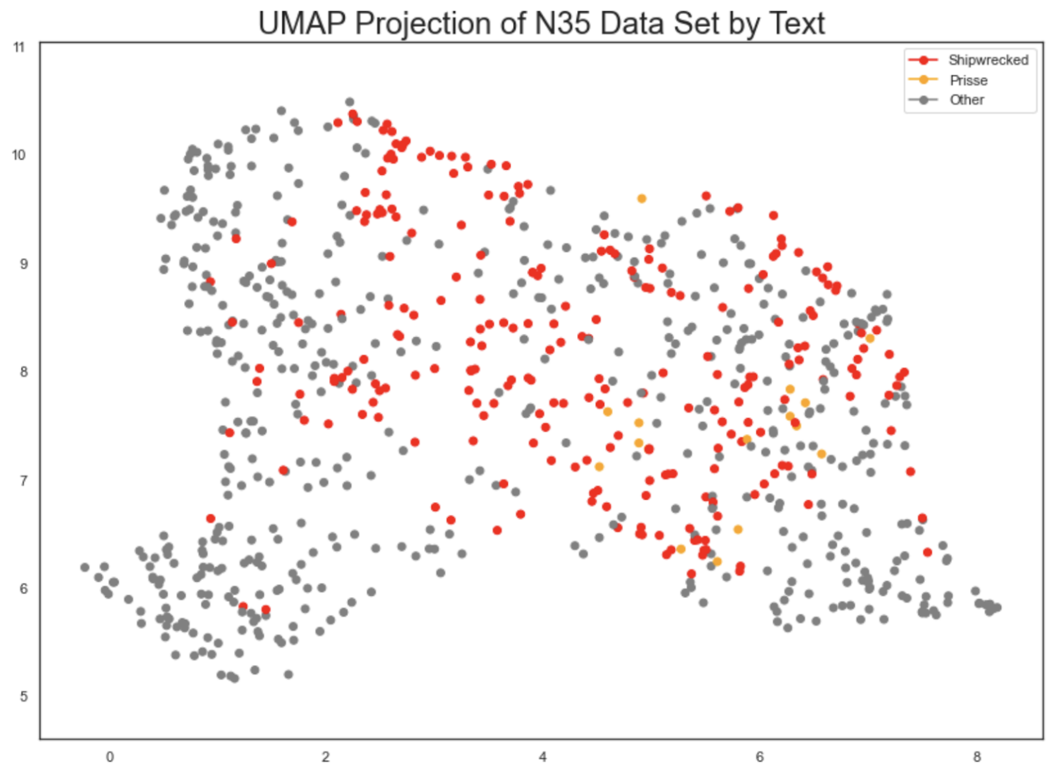

UMAP Projection of M17 Data Set by Text
Shipwrecked
Prisse
Other
10
9
8
7
6
5
4
3
2
−2
0
2
4
6
8
10

Figure 20


UMAP Projection of N35 Data Set by Text
Shipwrecked
Prisse
Other
11
10
9
8
7
6
5
0
2
4
6
8

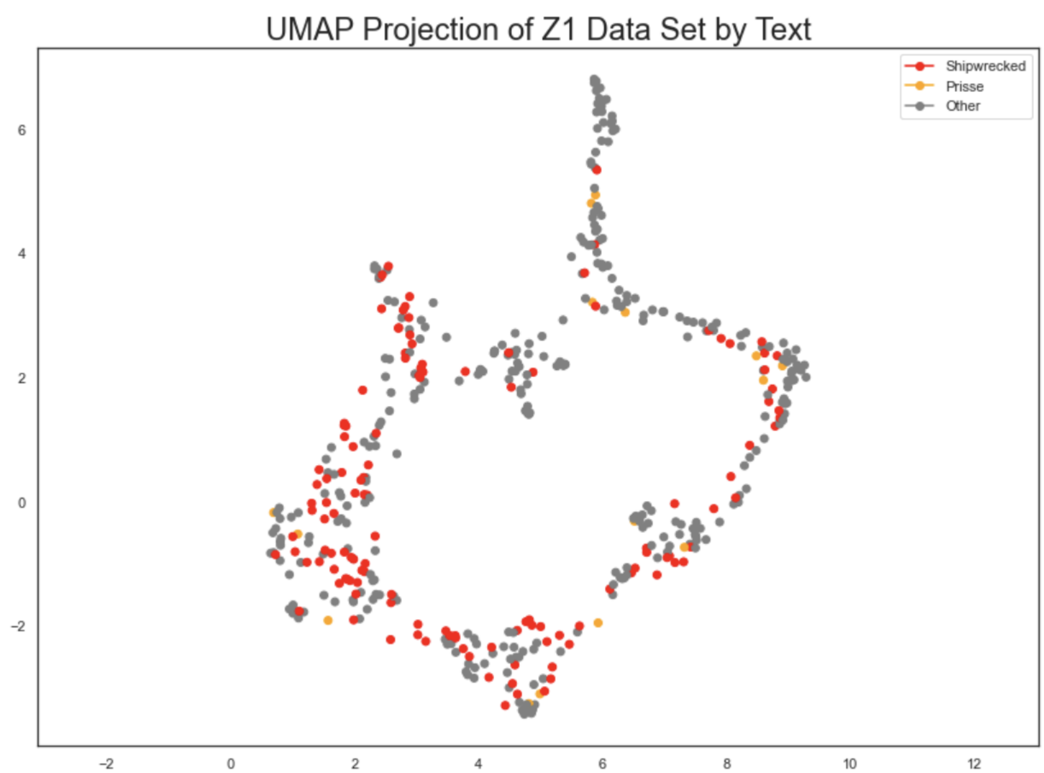
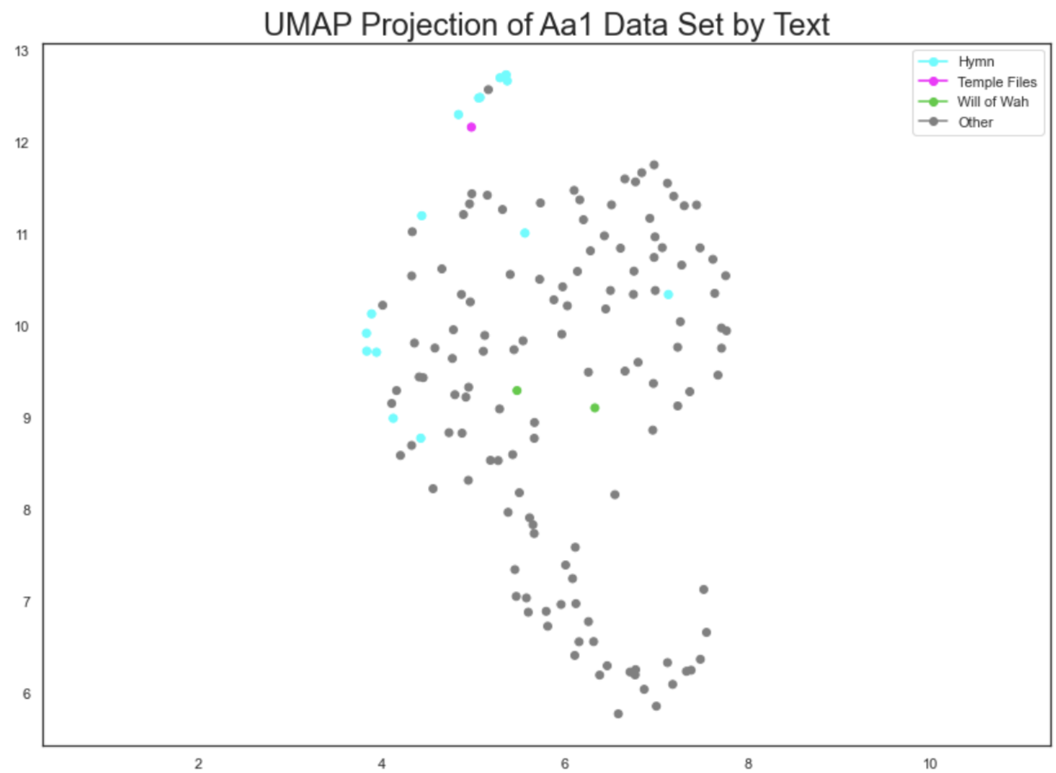

UMAP Projection of Z1 Data Set by Text
Shipwrecked
Prisse
Other
6
4
2
0
−2
−2
0
2
4
6
8
10
12

Figure 22


UMAP Projection of Aa1 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
13
12
11
10
9
8
7
6
2
4
6
8
10

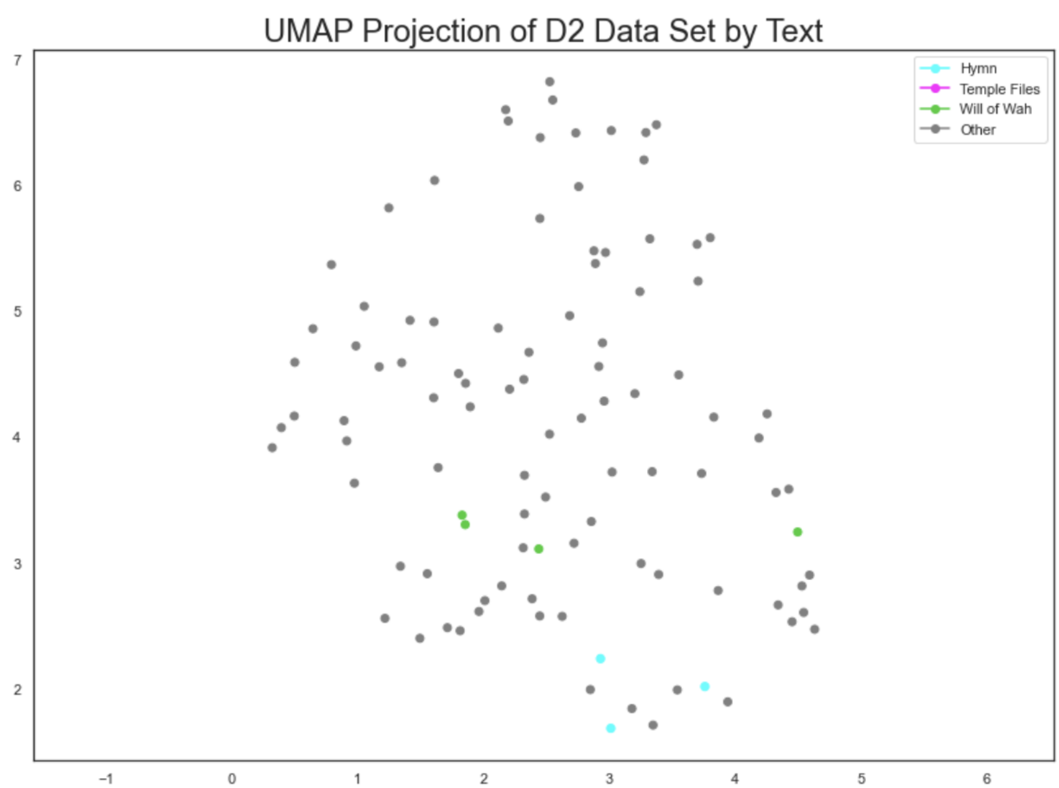

UMAP Projection of D2 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
7
6
5
4
3
2
−1
0
1
2
3
4
5
6

Figure 22

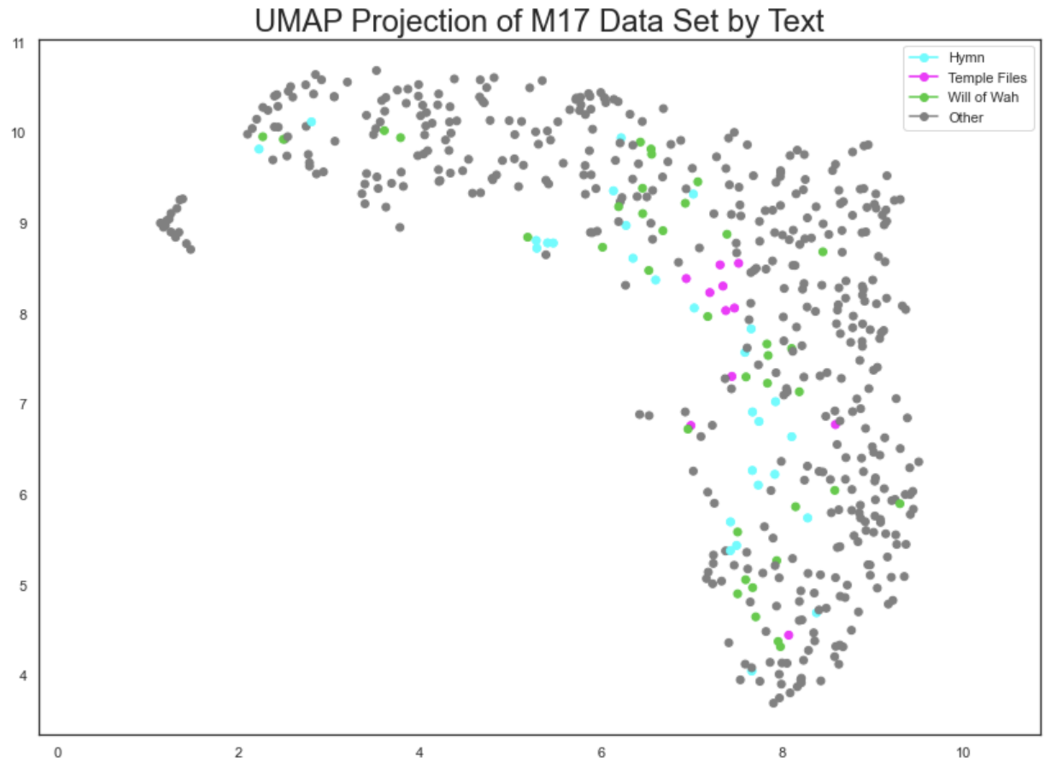
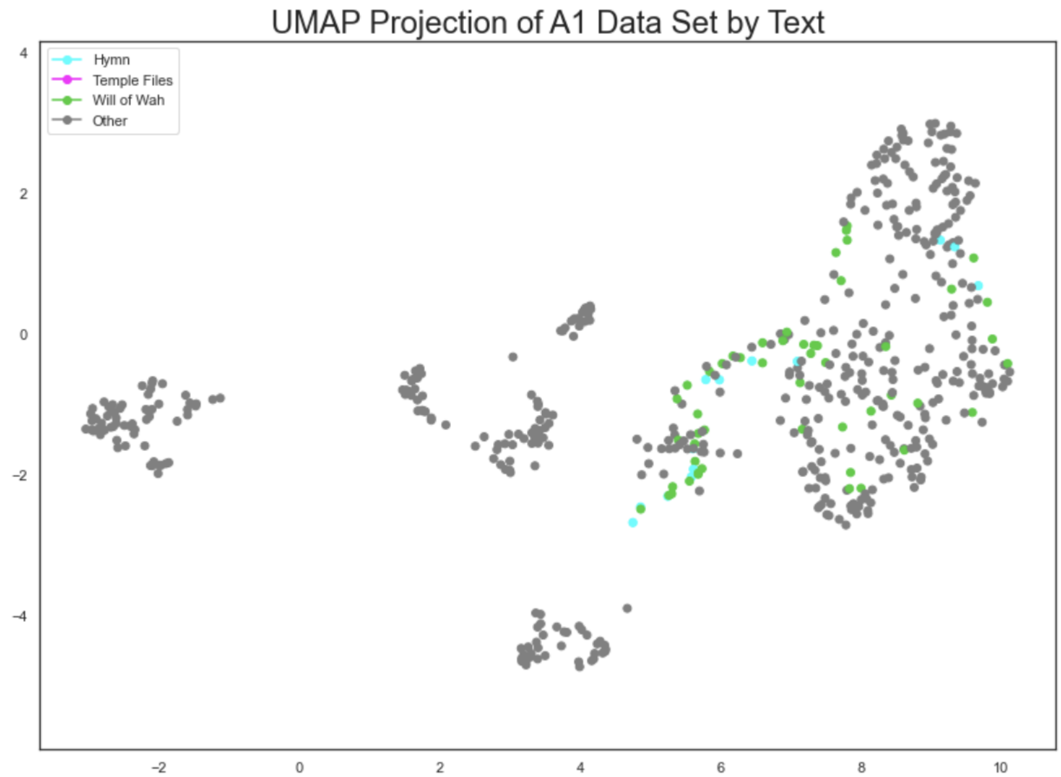

UMAP Projection of M17 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
11
10
9
8
7
6
5
4
0
2
4
6
8
10

Figure 24


UMAP Projection of A1 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
4
2
0
-2
-4
-2
0
2
4
6
8
10

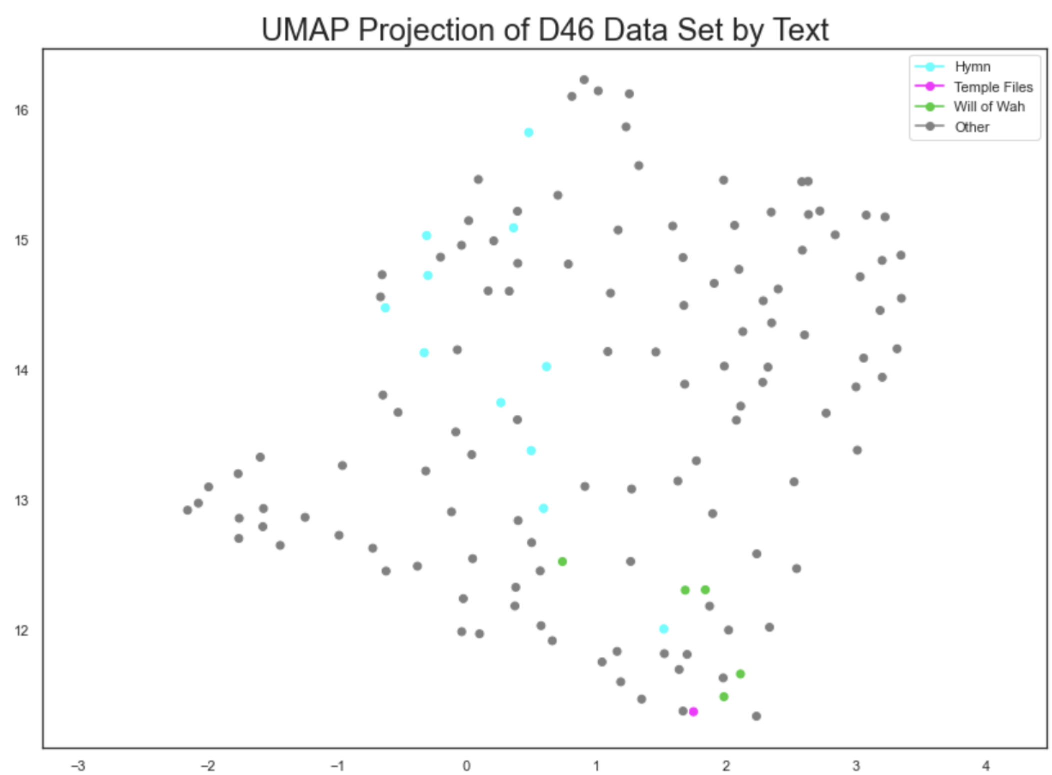

UMAP Projection of D46 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
16
15
14
13
12
-3
-2
-1
0
1
2
3
4

Figure 24

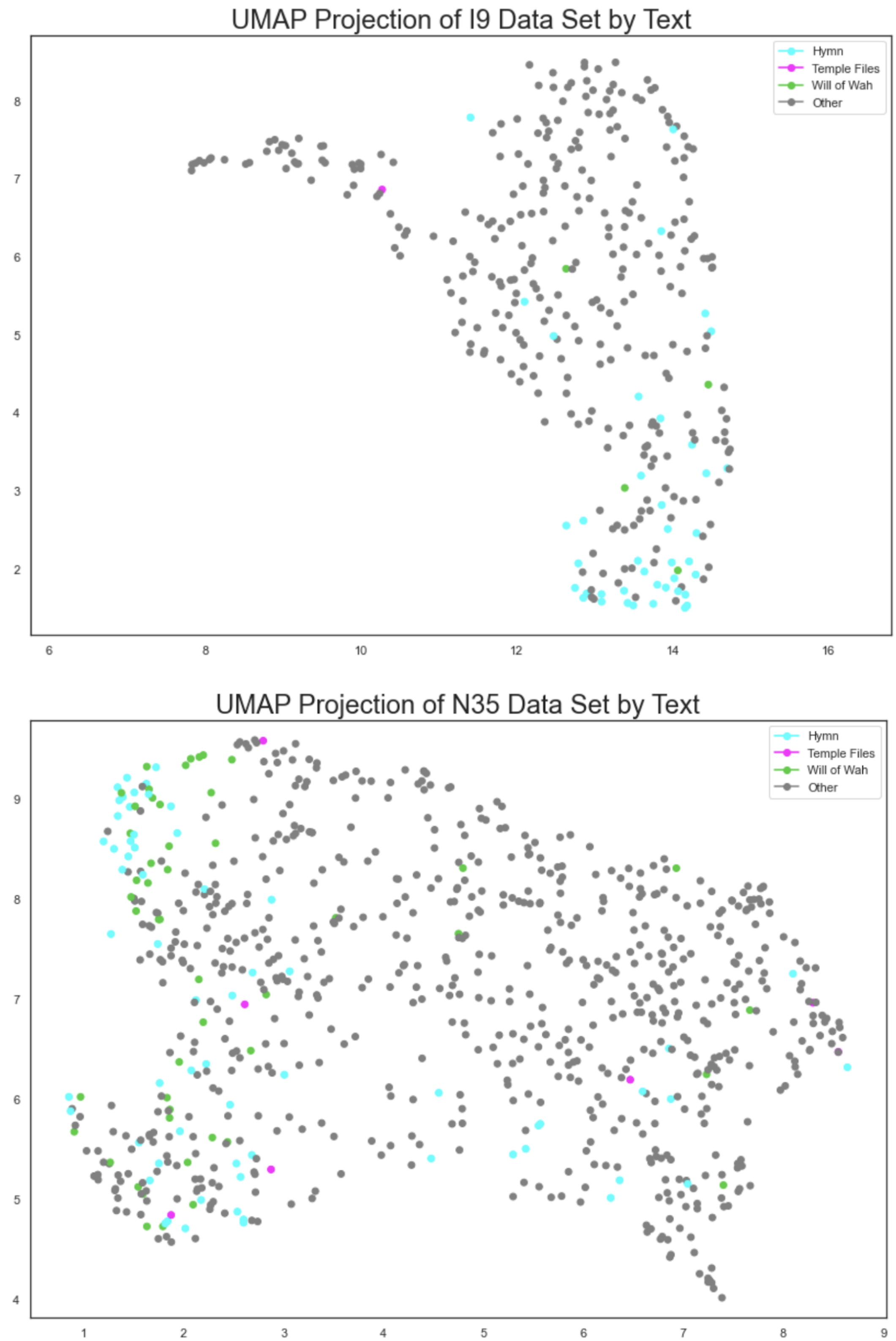
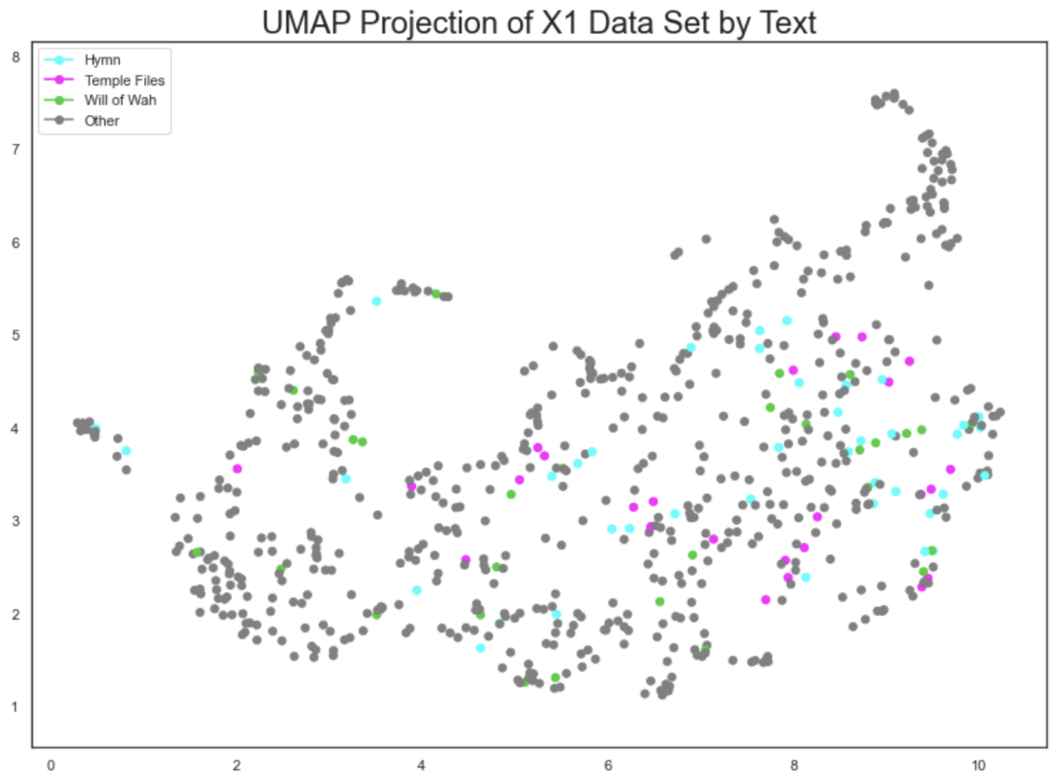

UMAP Projection of I9 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
8
7
6
5
4
3
2
6
8
10
12
14
16
UMAP Projection of N35 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
9
8
7
6
5
4
1
2
3
4
5
6
7
8
9

Figure 24


UMAP Projection of X1 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
8
7
6
5
4
3
2
1
0
2
4
6
8
10

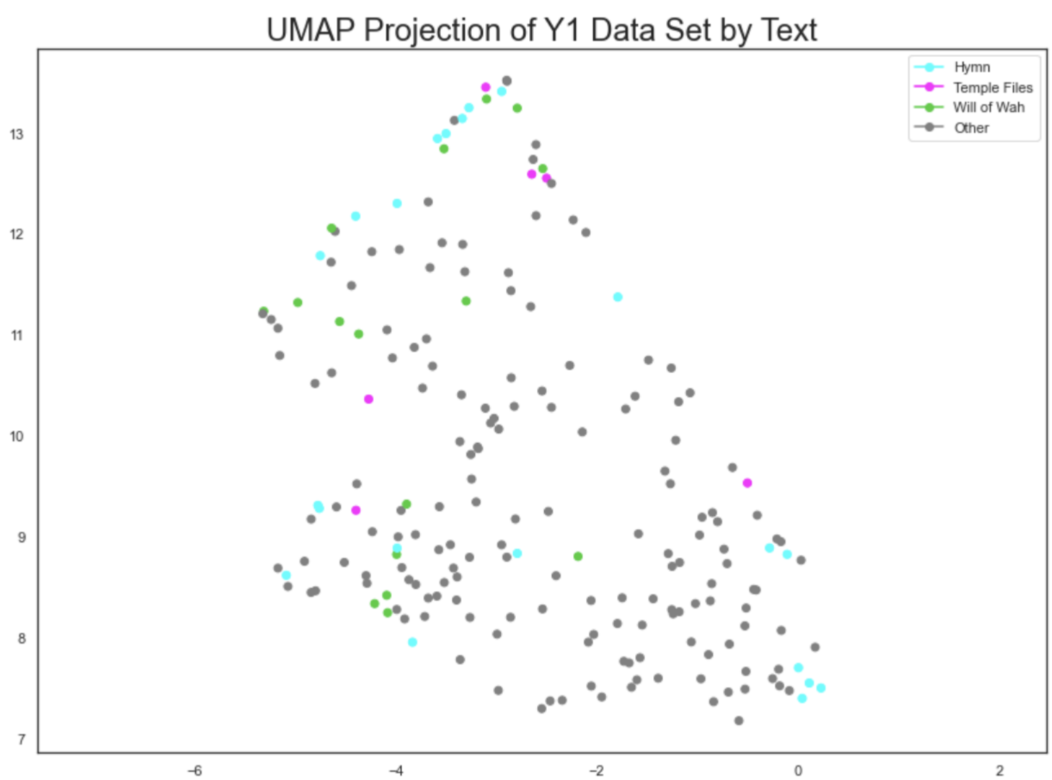
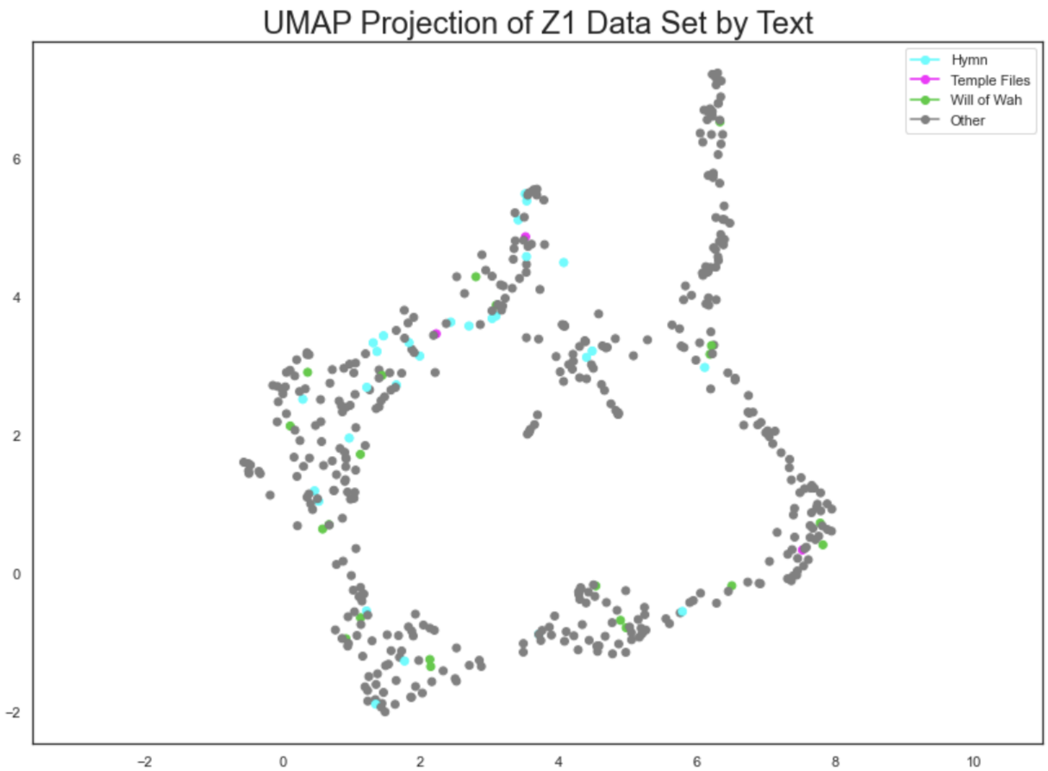

UMAP Projection of Y1 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
13
12
11
10
9
8
7
−6
−4
−2
0
2

Figure 24


UMAP Projection of Z1 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
6
4
2
0
−2
−2
0
2
4
6
8
10

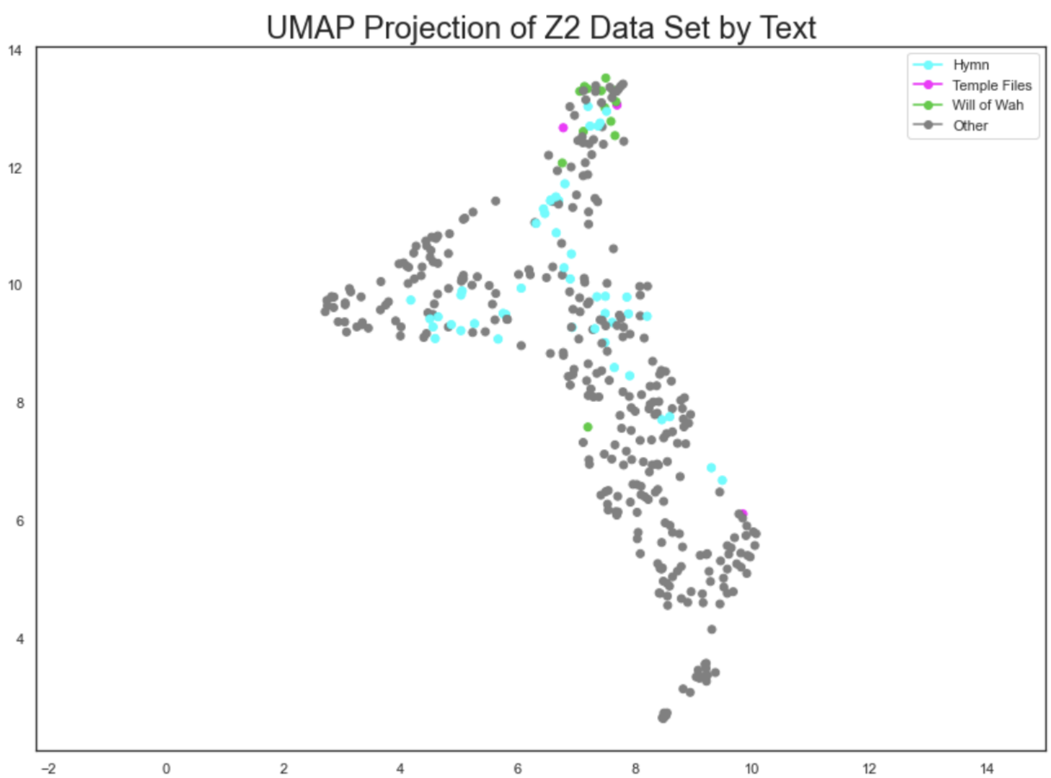
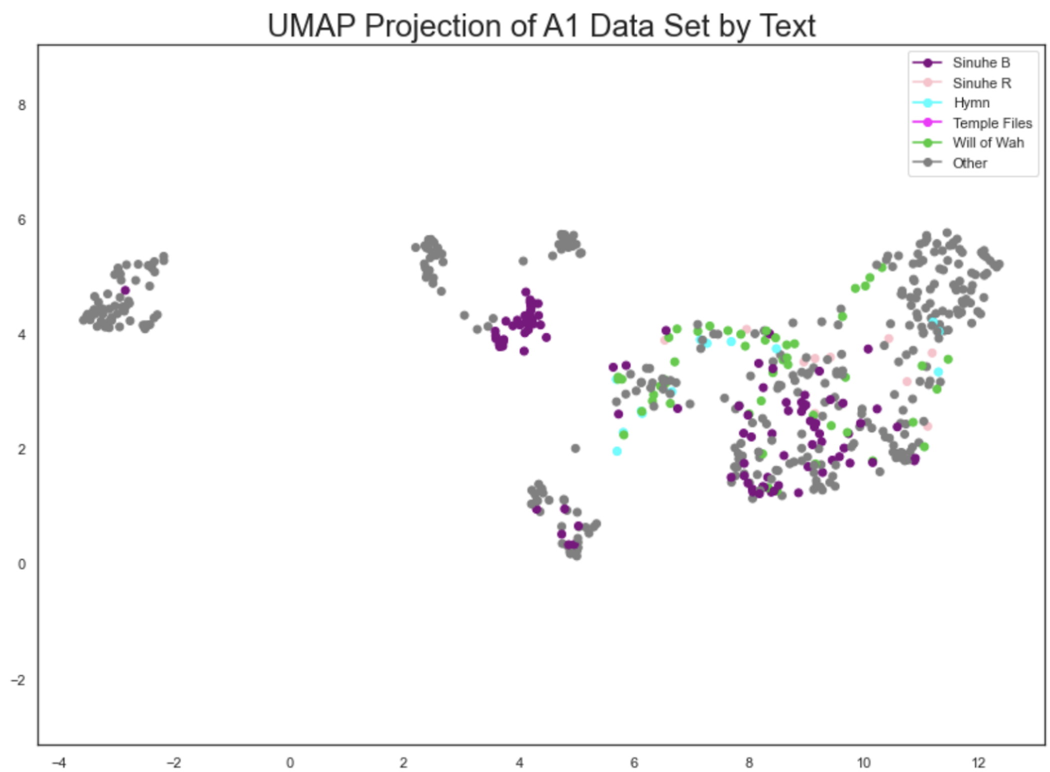

UMAP Projection of Z2 Data Set by Text
Hymn
Temple Files
Will of Wah
Other
14
12
10
8
6
4
−2
0
2
4
6
8
10
12
14

Figure 28


UMAP Projection of A1 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other

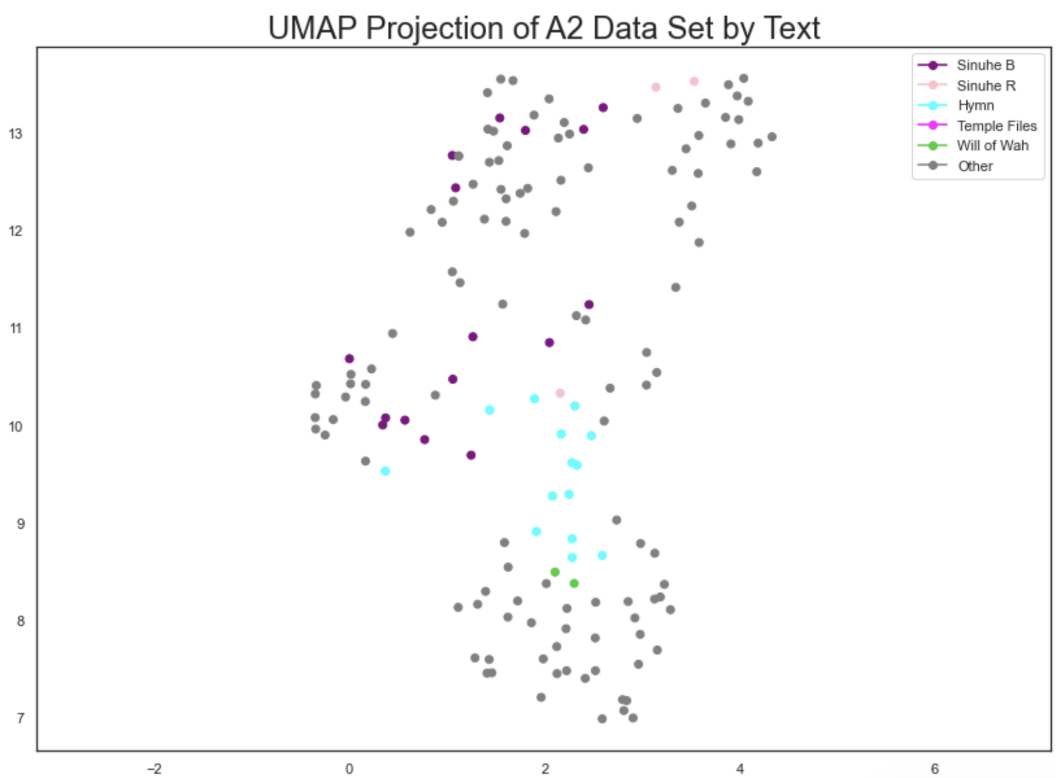
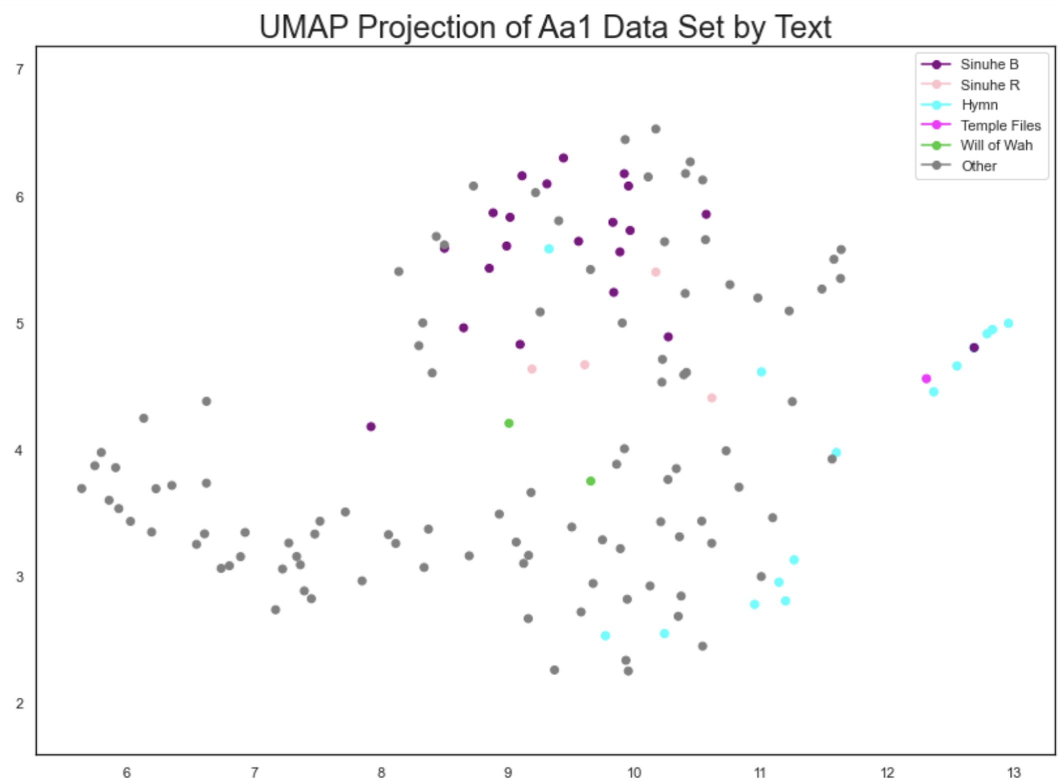

UMAP Projection of A2 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other

Figure 28


UMAP Projection of Aa1 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
7
6
5
4
3
2
6
7
8
9
10
11
12
13

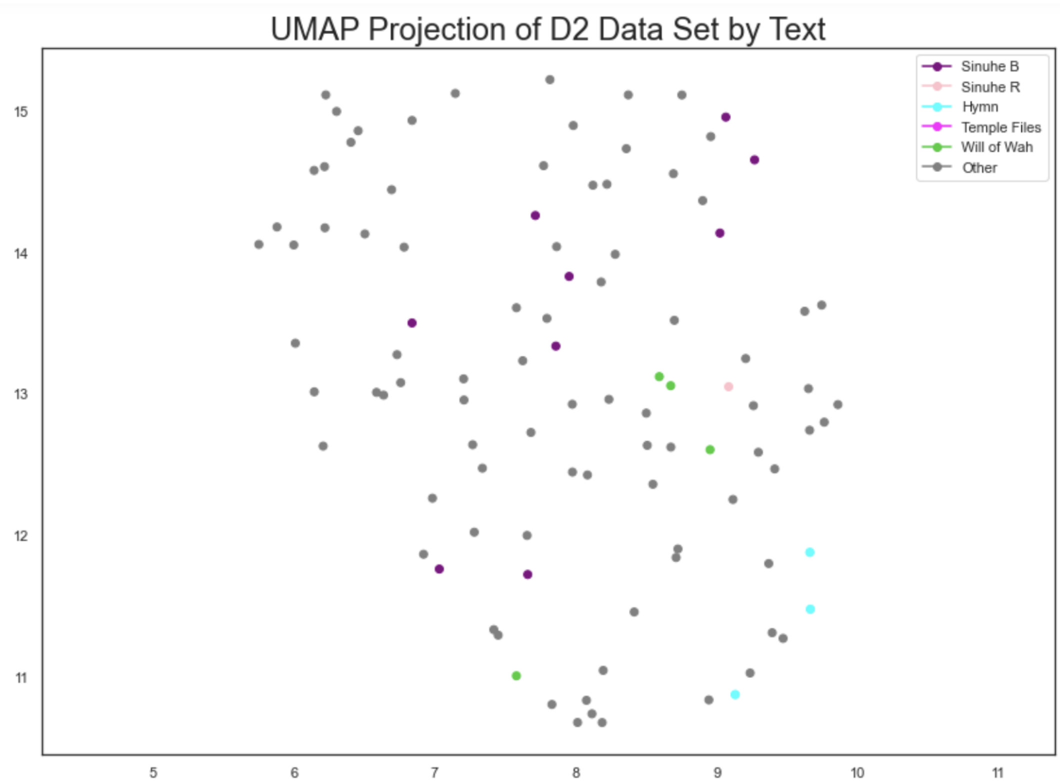
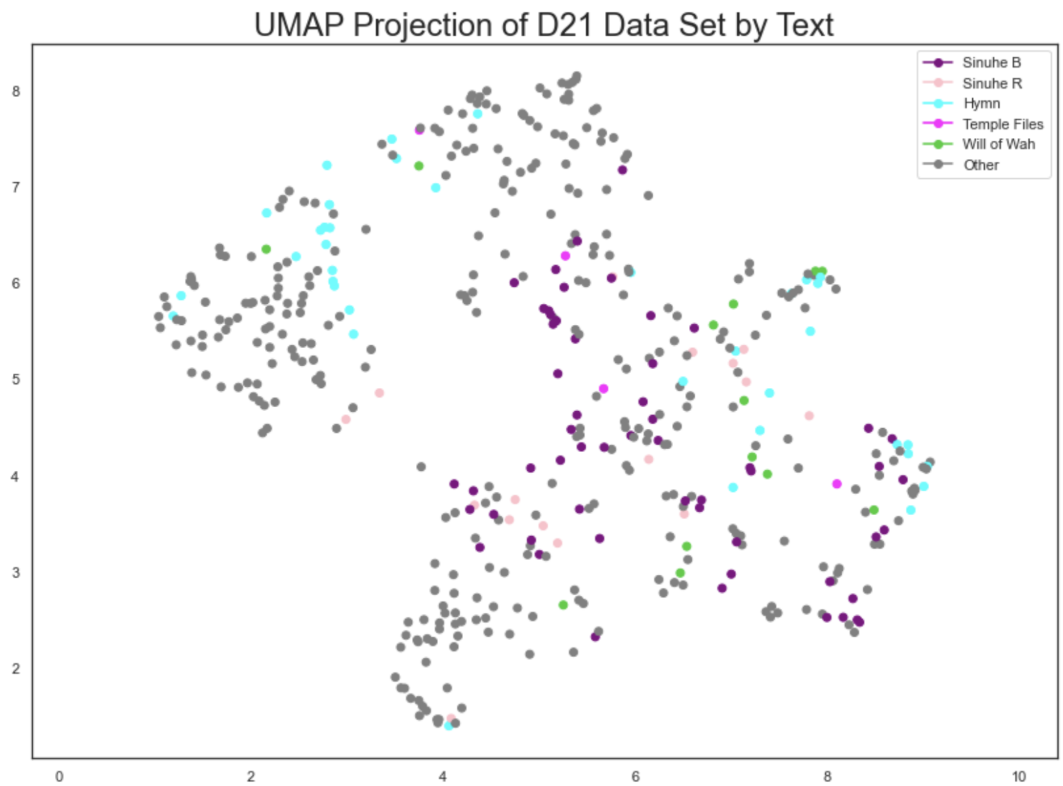

UMAP Projection of D2 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
15
14
13
12
11
5
6
7
8
9
10
11

Figure 28


UMAP Projection of D21 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
0
2
4
6
8
10
2
3
4
5
6
7
8

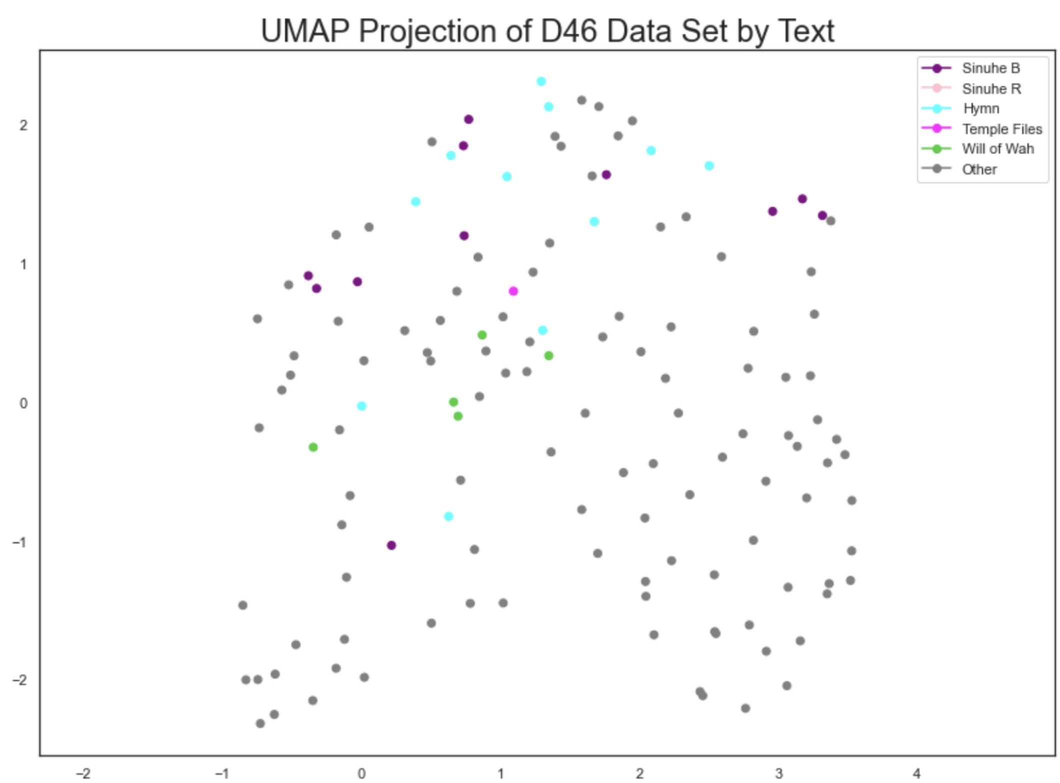
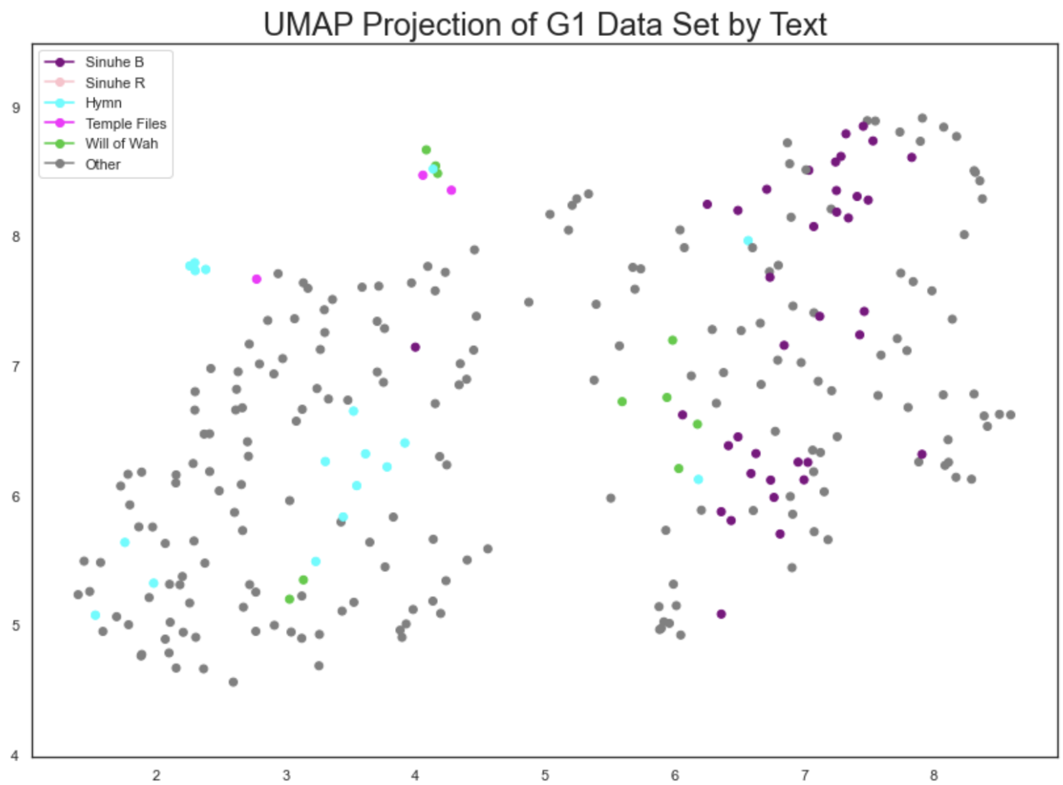

UMAP Projection of D46 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
−2
−1
0
1
2
3
4
−2
−1
0
1
2

Figure 28


UMAP Projection of G1 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
9
8
7
6
5
4
2
3
4
5
6
7
8

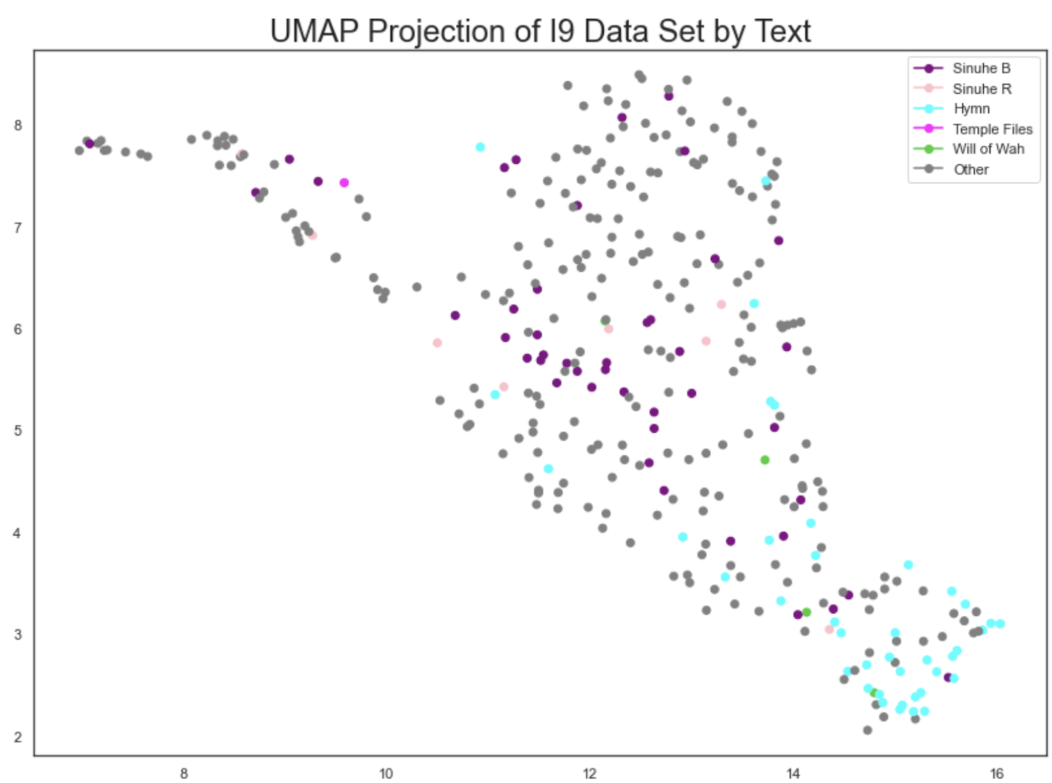
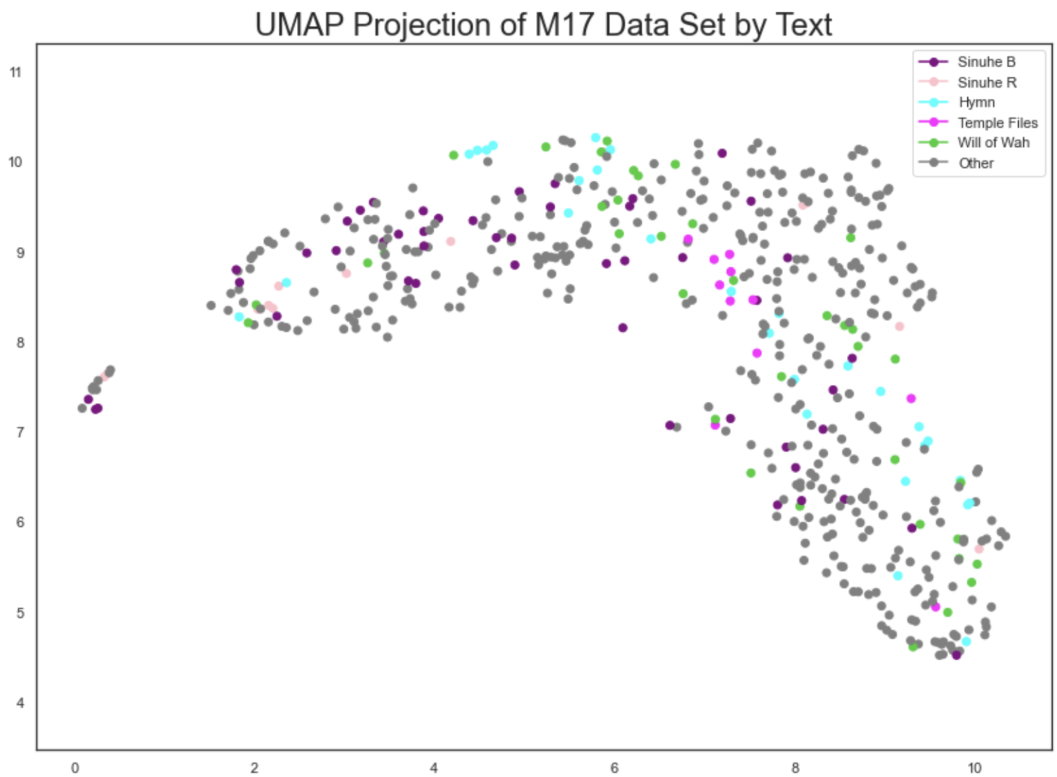
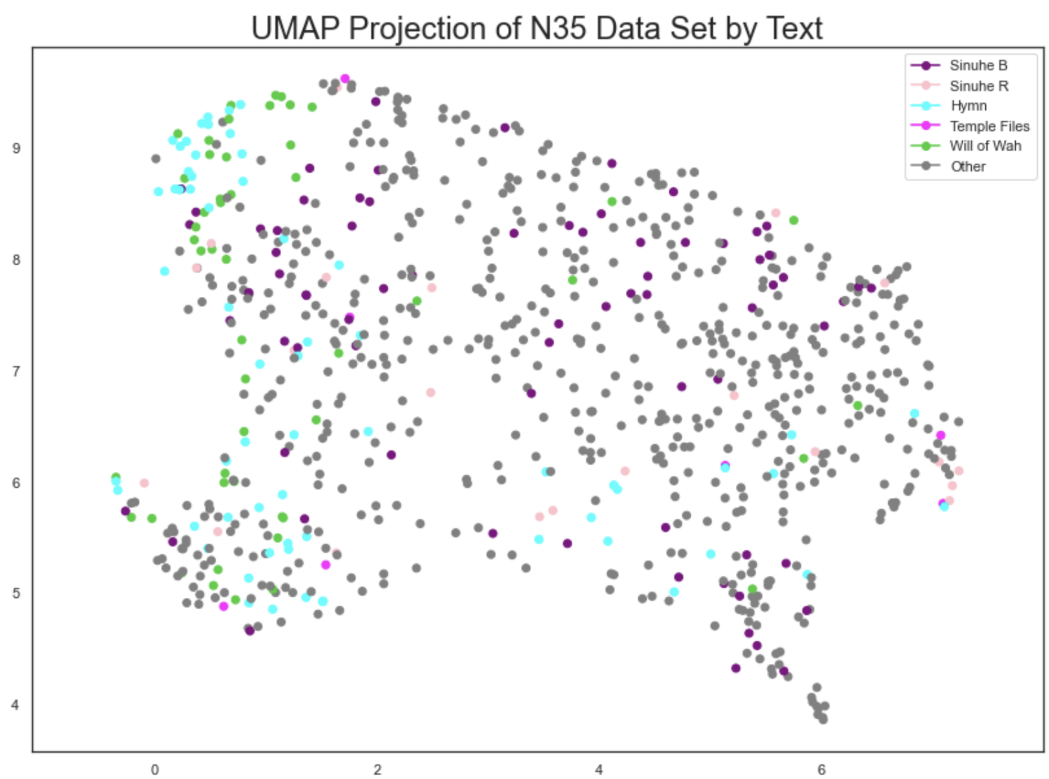

UMAP Projection of I9 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
8
7
6
5
4
3
2
8
10
12
14
16

Figure 28

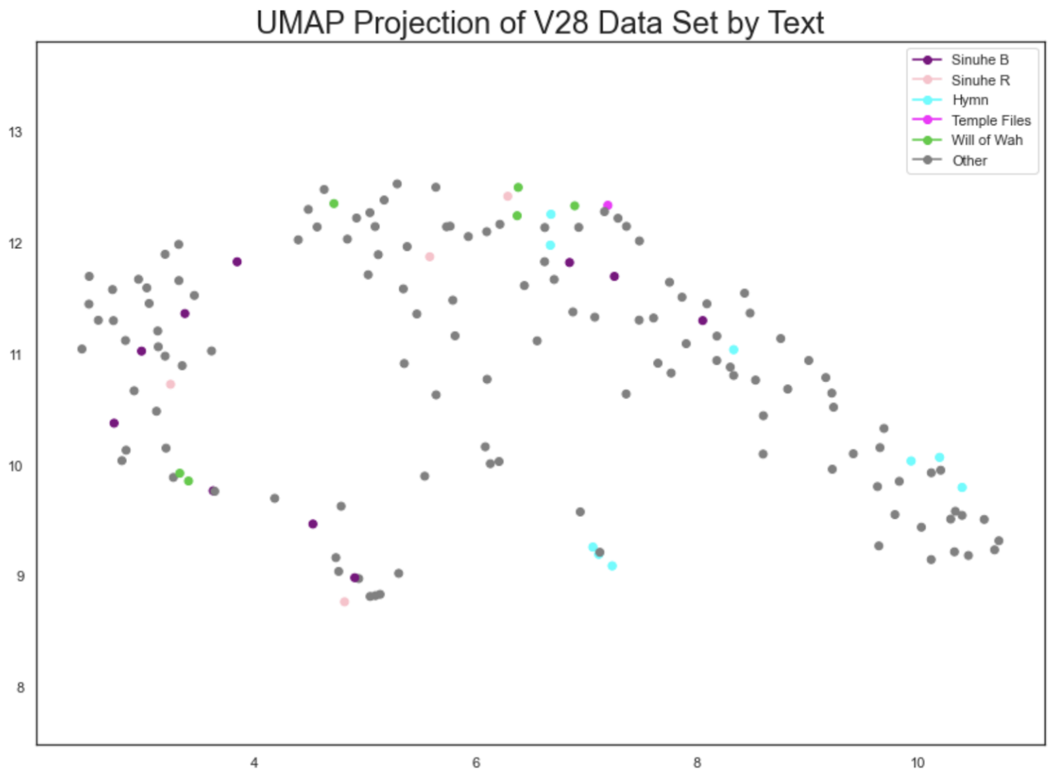


UMAP Projection of M17 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
11
10
9
8
7
6
5
4
0
2
4
6
8
10



UMAP Projection of N35 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
9
8
7
6
5
4
0
2
4
6

Figure 28


UMAP Projection of V28 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
13
12
11
10
9
8
4
6
8
10

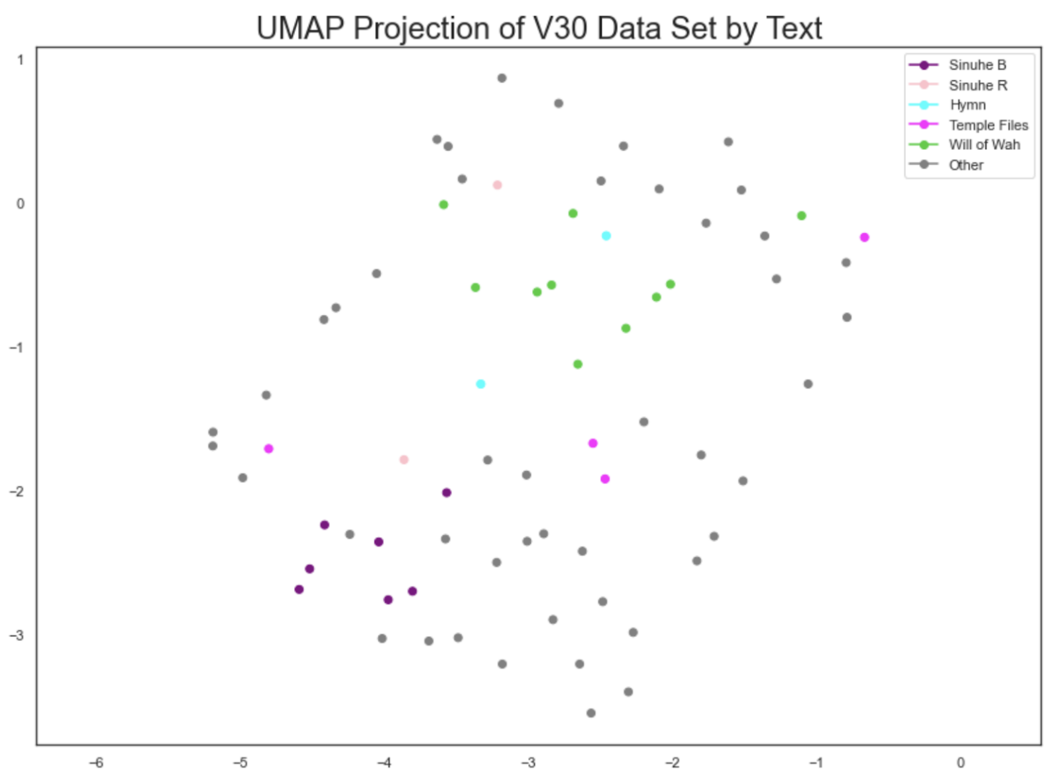
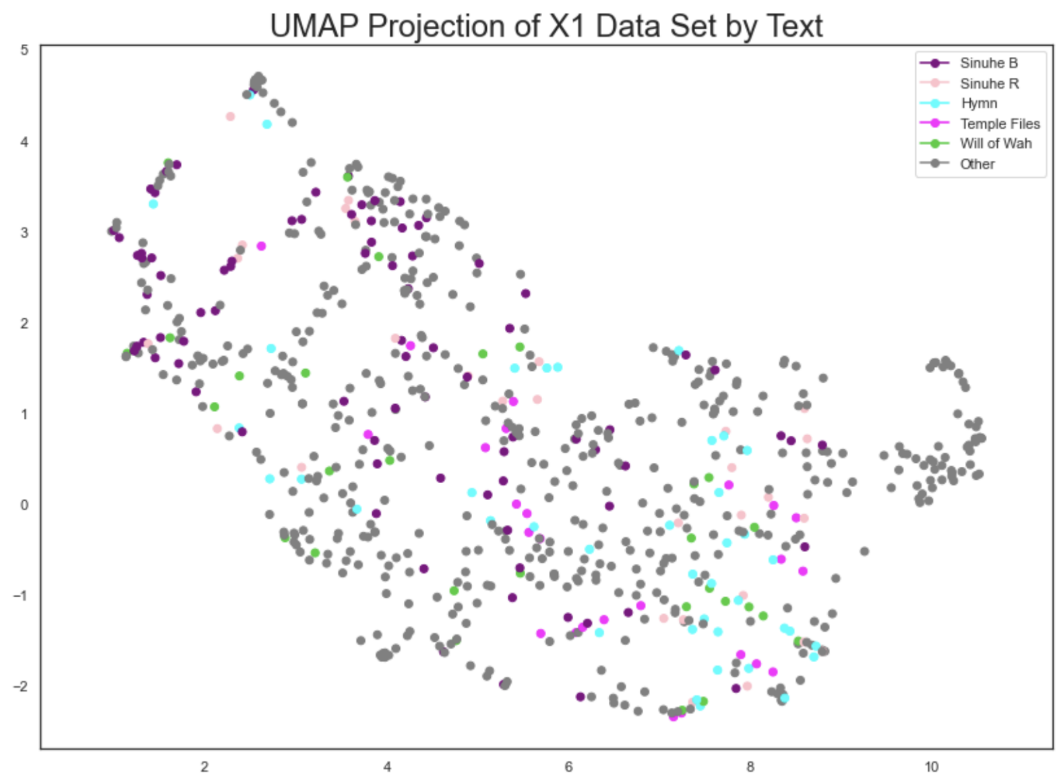

UMAP Projection of V30 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
1
0
−1
−2
−3
−6
−5
−4
−3
−2
−1
0

Figure 28


UMAP Projection of X1 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
5
4
3
2
1
0
−1
−2
2
4
6
8
10

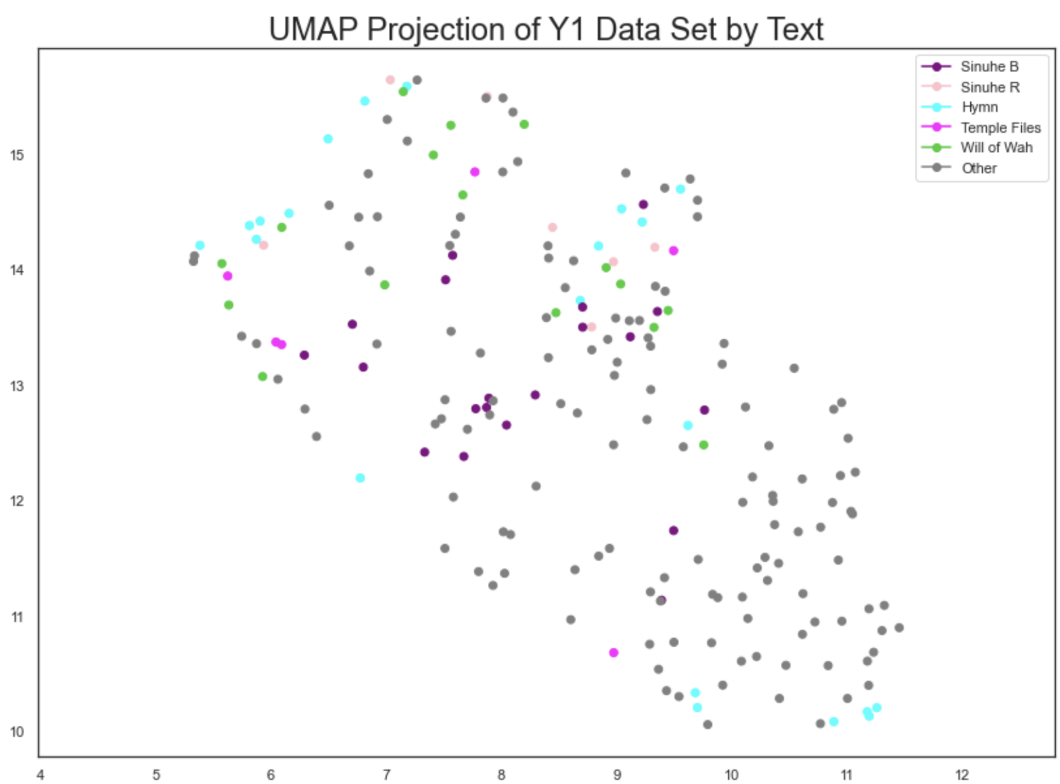
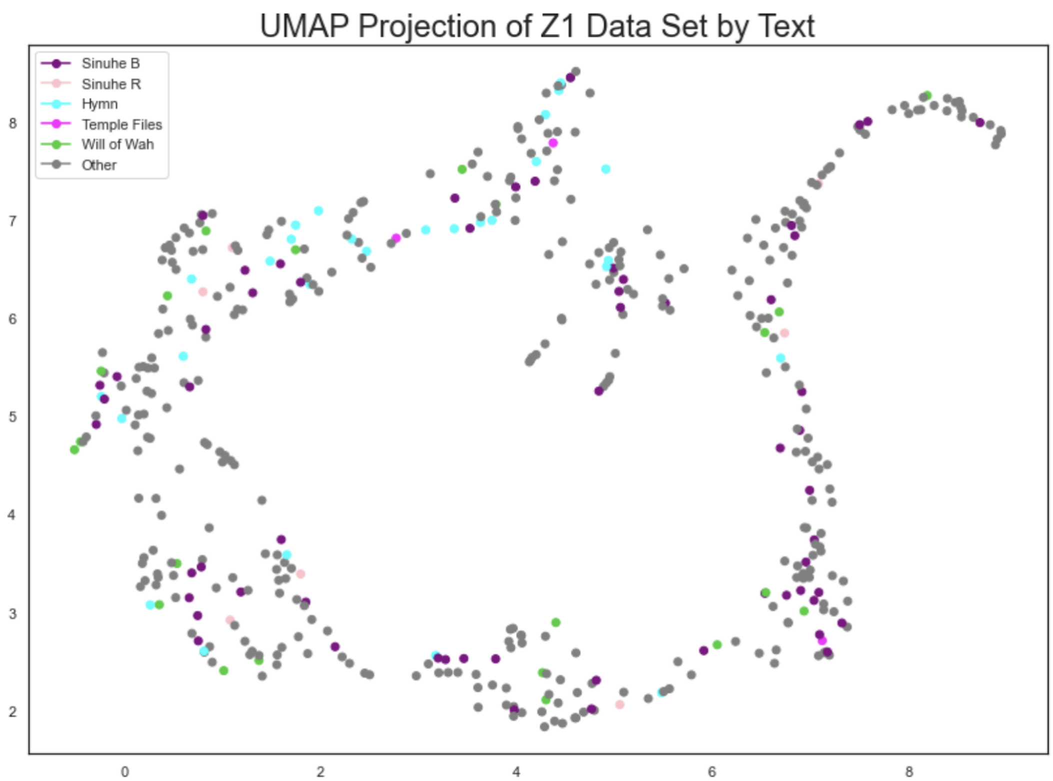

UMAP Projection of Y1 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
15
14
13
12
11
10
4
5
6
7
8
9
10
11
12

Figure 28


UMAP Projection of Z1 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
2
3
4
5
6
7
8
0
2
4
6
8

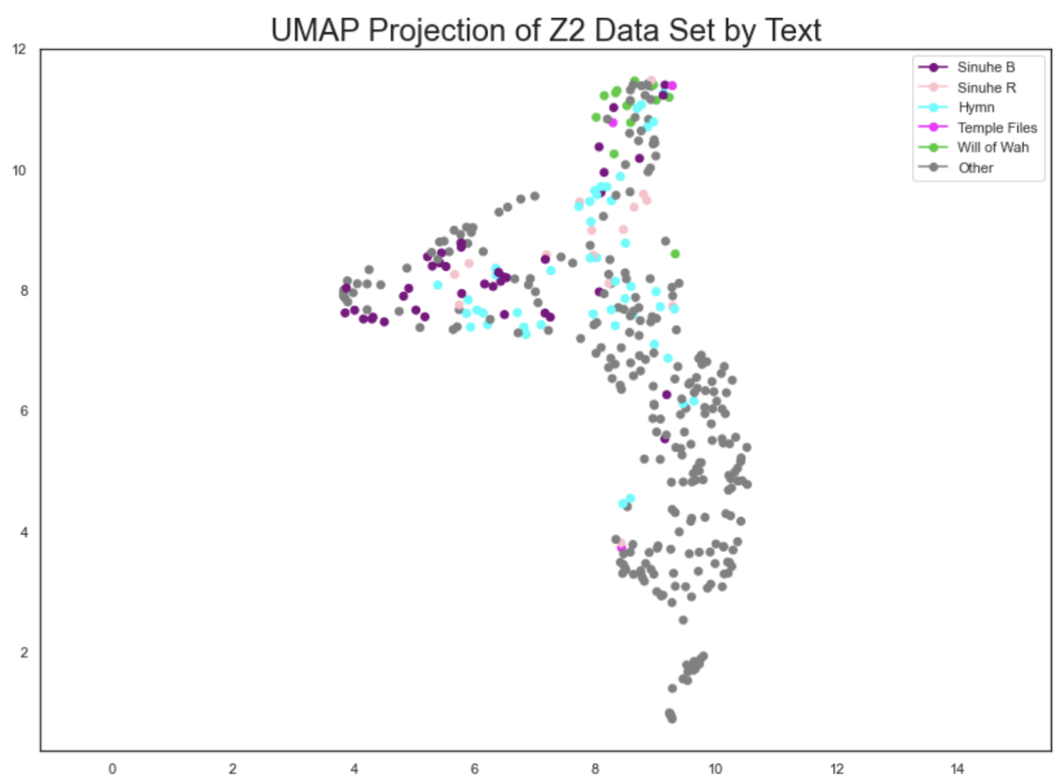
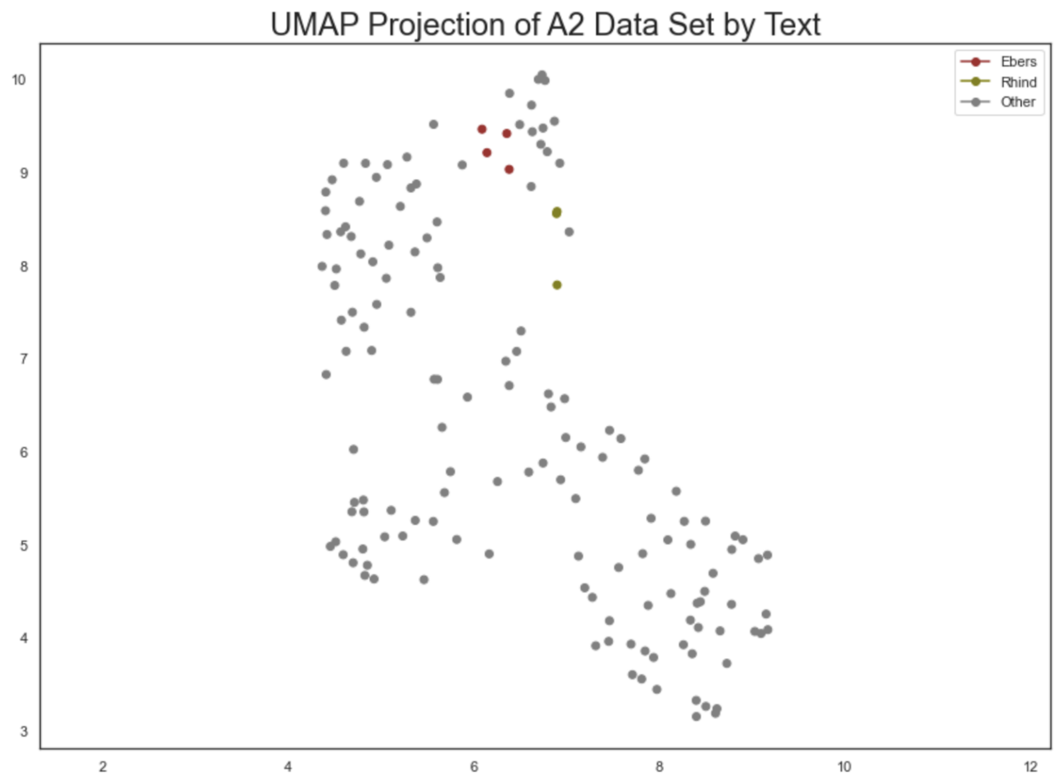

UMAP Projection of Z2 Data Set by Text
Sinuhe B
Sinuhe R
Hymn
Temple Files
Will of Wah
Other
2
4
6
8
10
12
0
2
4
6
8
10
12
14

Figure 30


UMAP Projection of A2 Data Set by Text
Ebers
Rhind
Other
10
9
8
7
6
5
4
3
2
4
6
8
10
12

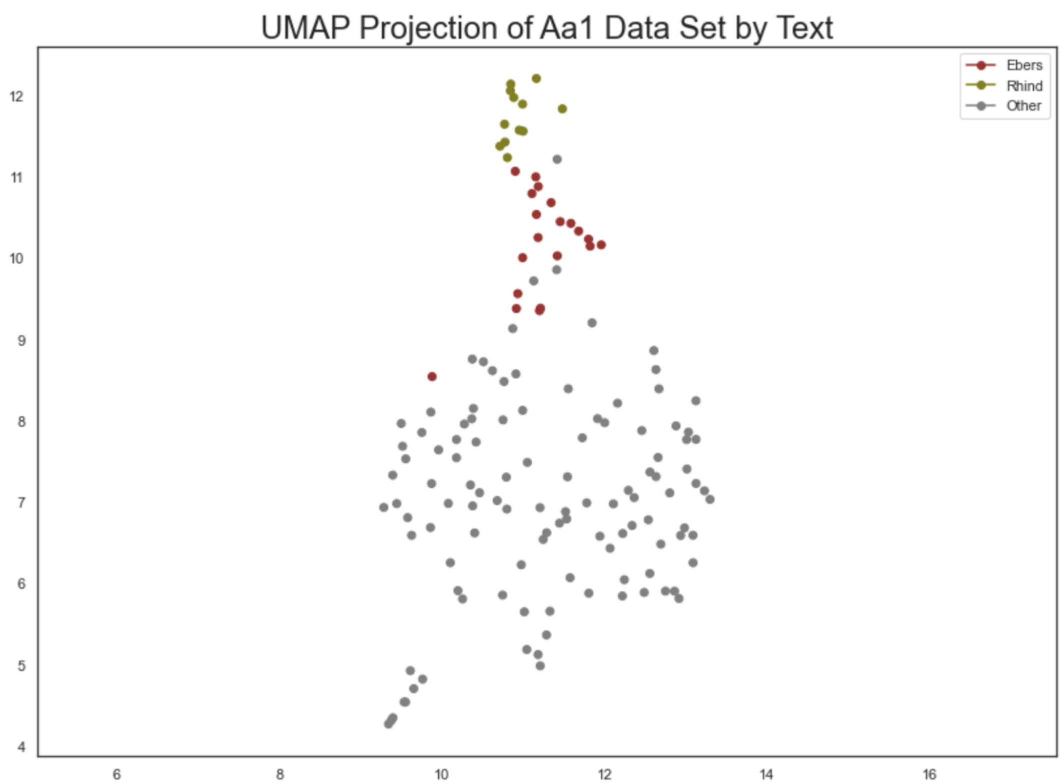
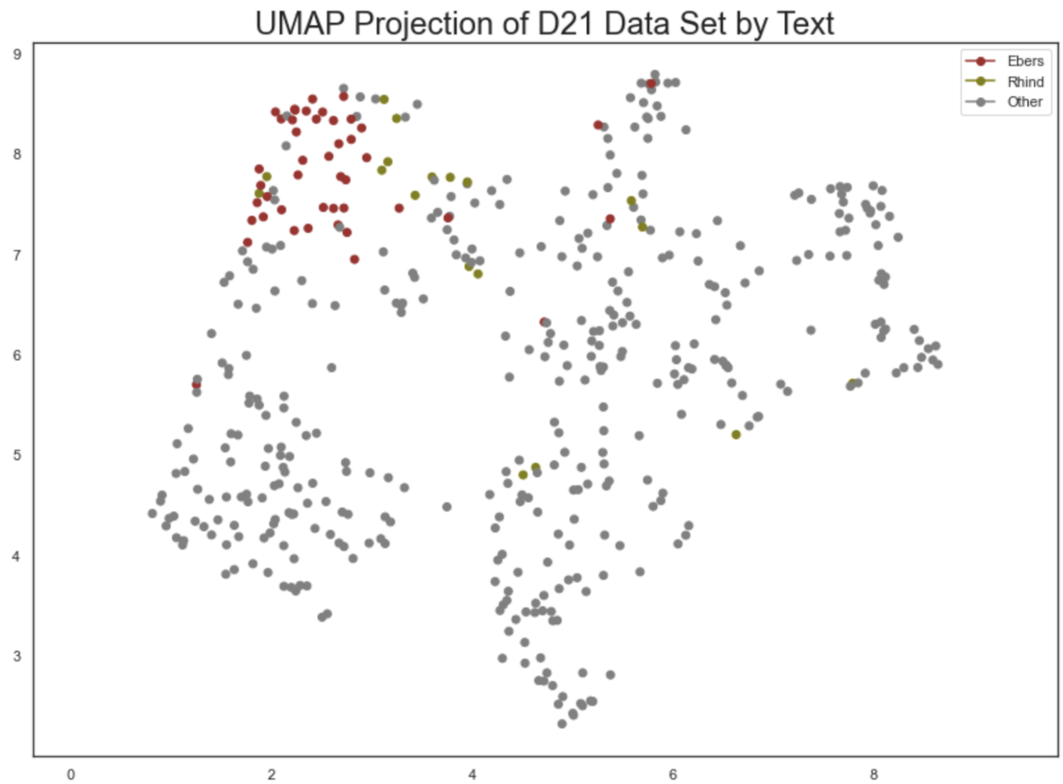

UMAP Projection of Aa1 Data Set by Text
Ebers
Rhind
Other
12
11
10
9
8
7
6
5
4
6
8
10
12
14
16

Figure 30


UMAP Projection of D21 Data Set by Text
Ebers
Rhind
Other
9
8
7
6
5
4
3
0
2
4
6
8

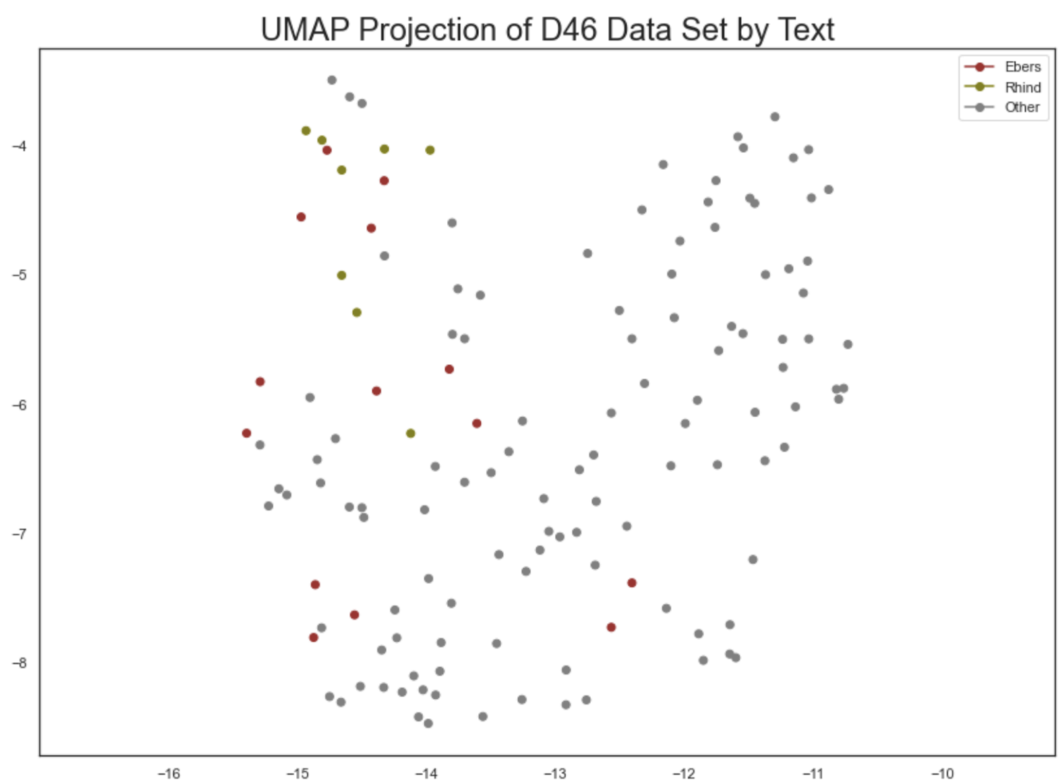
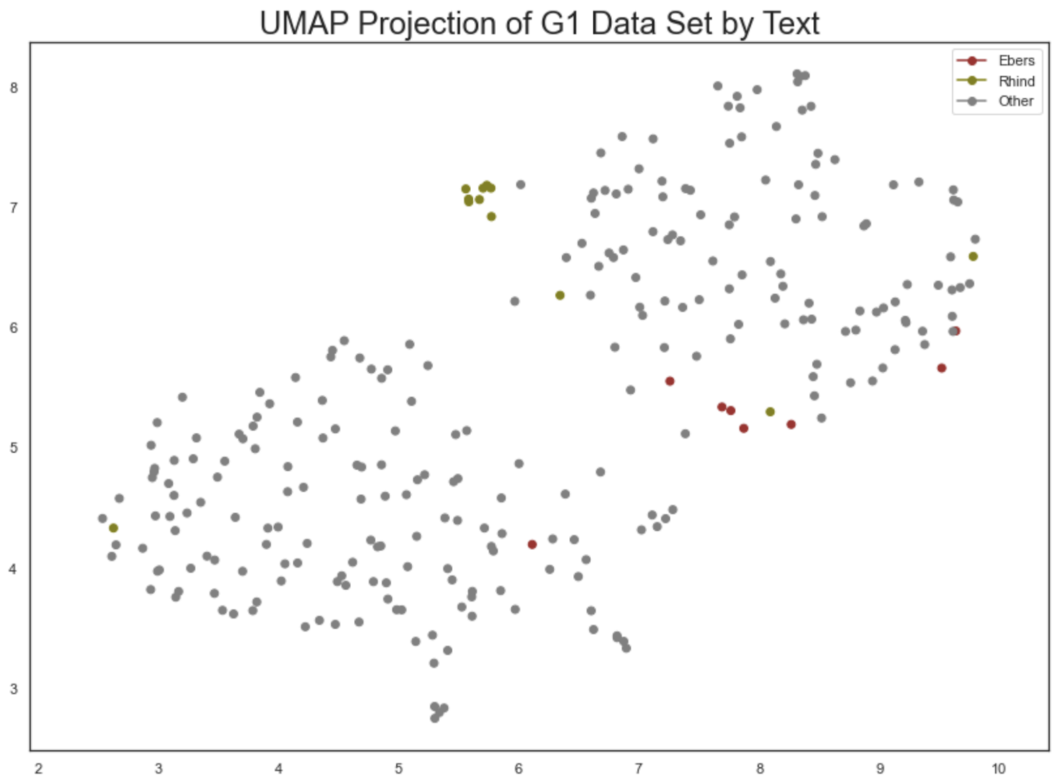

UMAP Projection of D46 Data Set by Text
Ebers
Rhind
Other
-4
-5
-6
-7
-8
-16
-15
-14
-13
-12
-11
-10

Figure 30


UMAP Projection of G1 Data Set by Text
Ebers
Rhind
Other
8
7
6
5
4
3
2
3
4
5
6
7
8
9
10

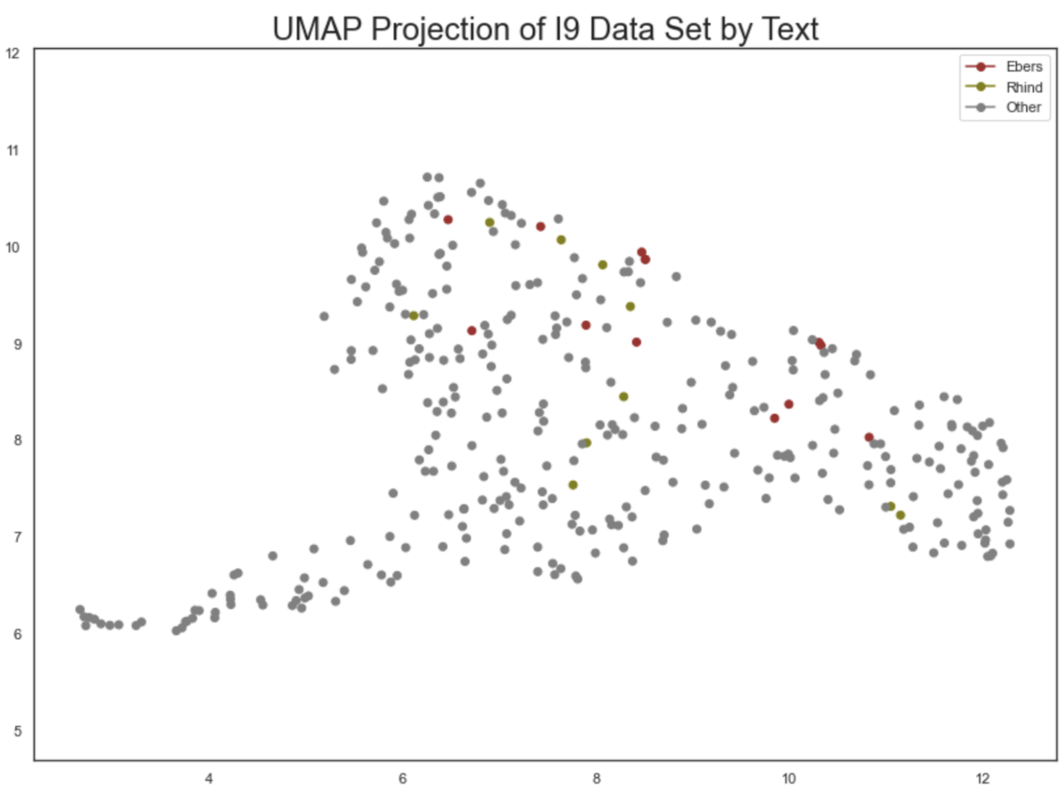
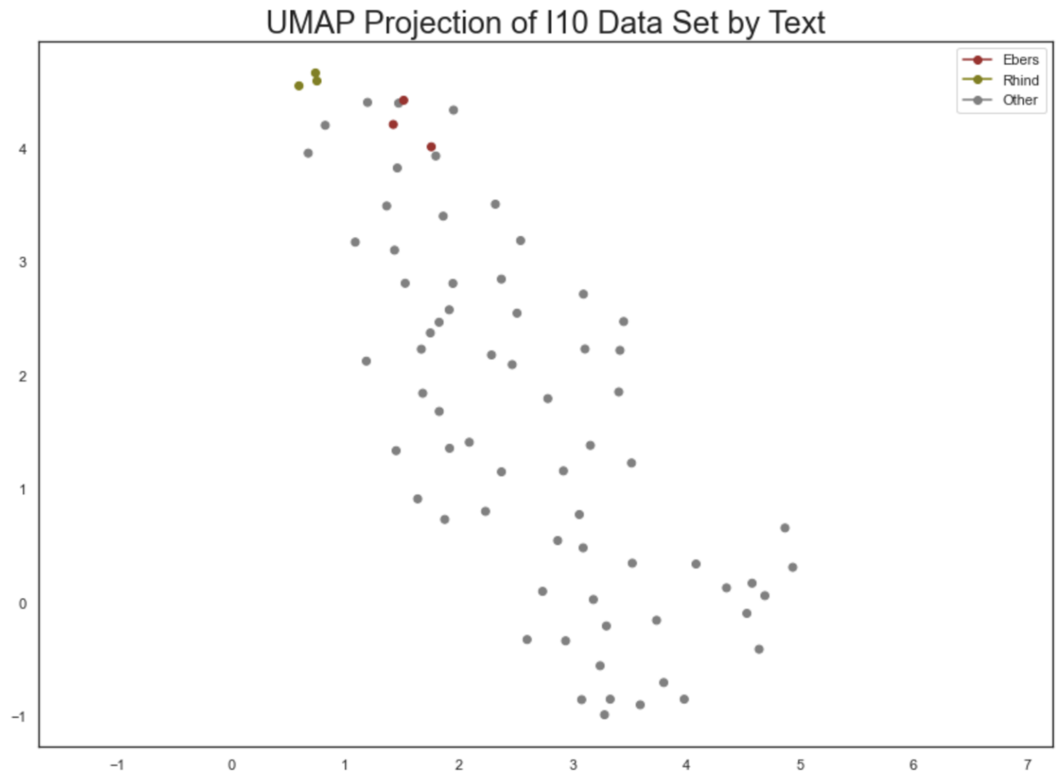

UMAP Projection of I9 Data Set by Text
Ebers
Rhind
Other
12
11
10
9
8
7
6
5
4
6
8
10
12

Figure 30


UMAP Projection of I10 Data Set by Text
Ebers
Rhind
Other
4
3
2
1
0
−1
−1
0
1
2
3
4
5
6
7

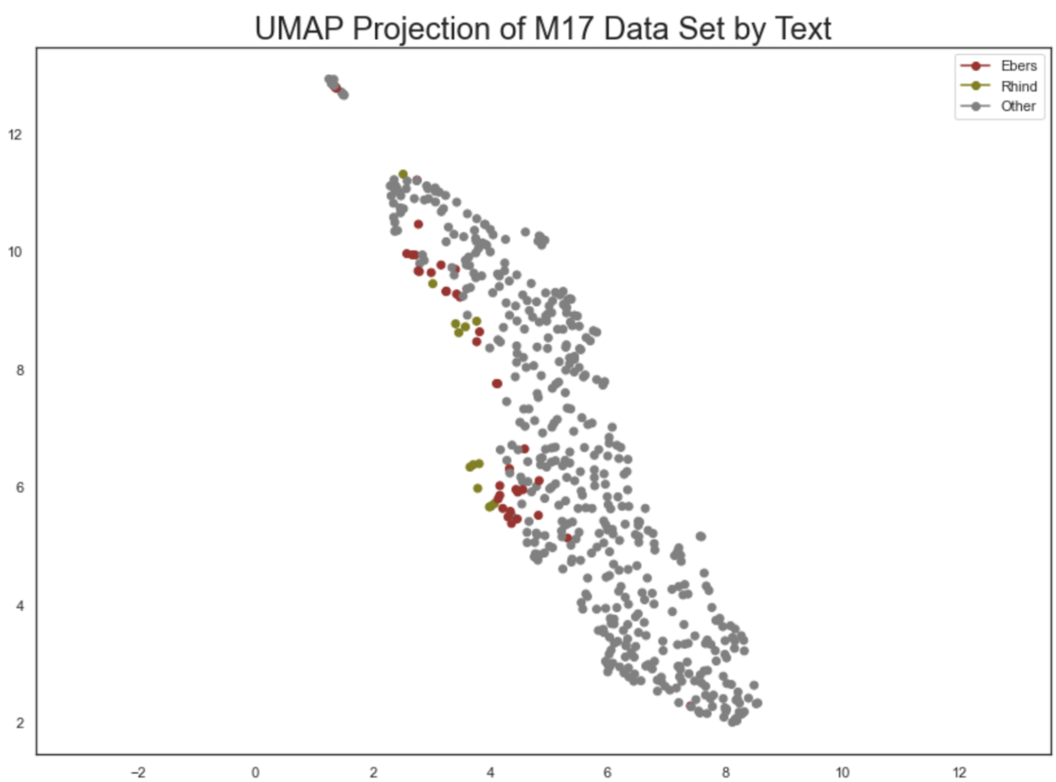
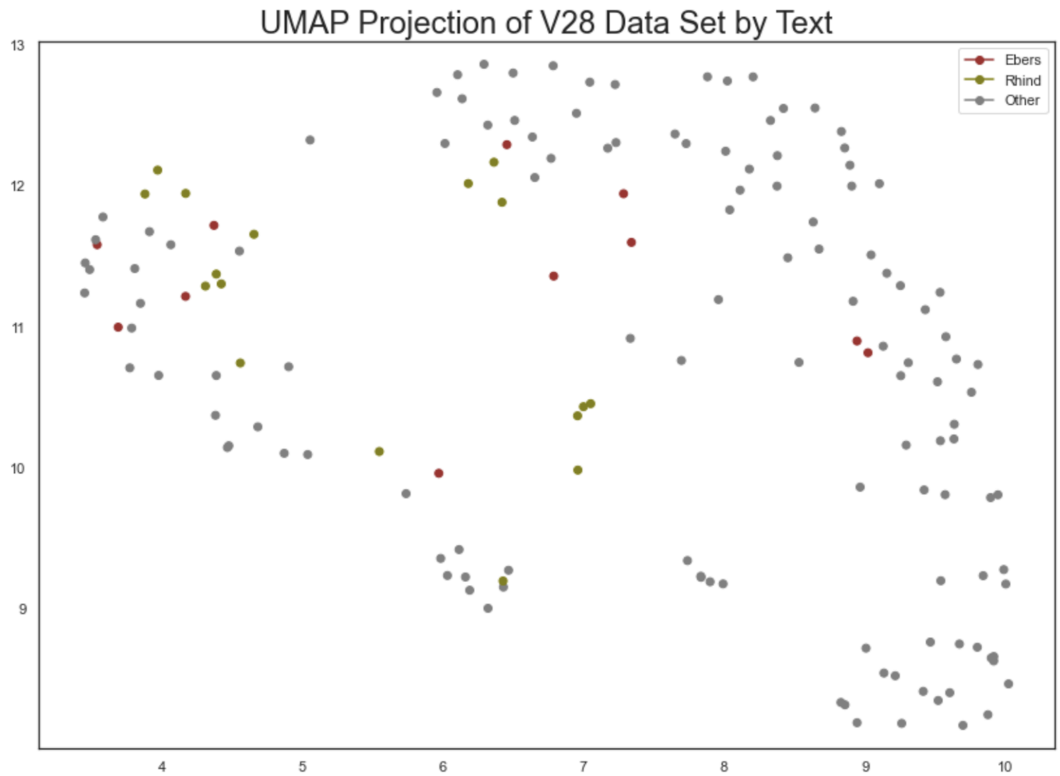

UMAP Projection of M17 Data Set by Text
Ebers
Rhind
Other
12
10
8
6
4
2
−2
0
2
4
6
8
10
12

Figure 30


UMAP Projection of V28 Data Set by Text
Ebers
Rhind
Other
13
12
11
10
9
4
5
6
7
8
9
10

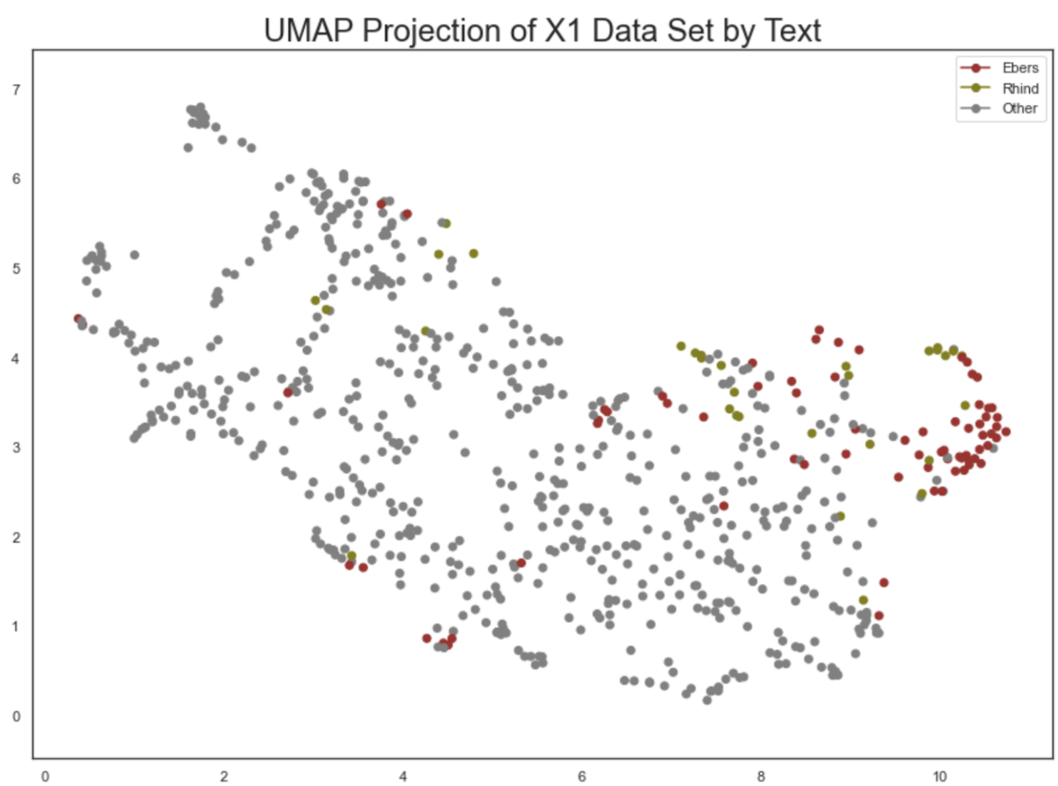
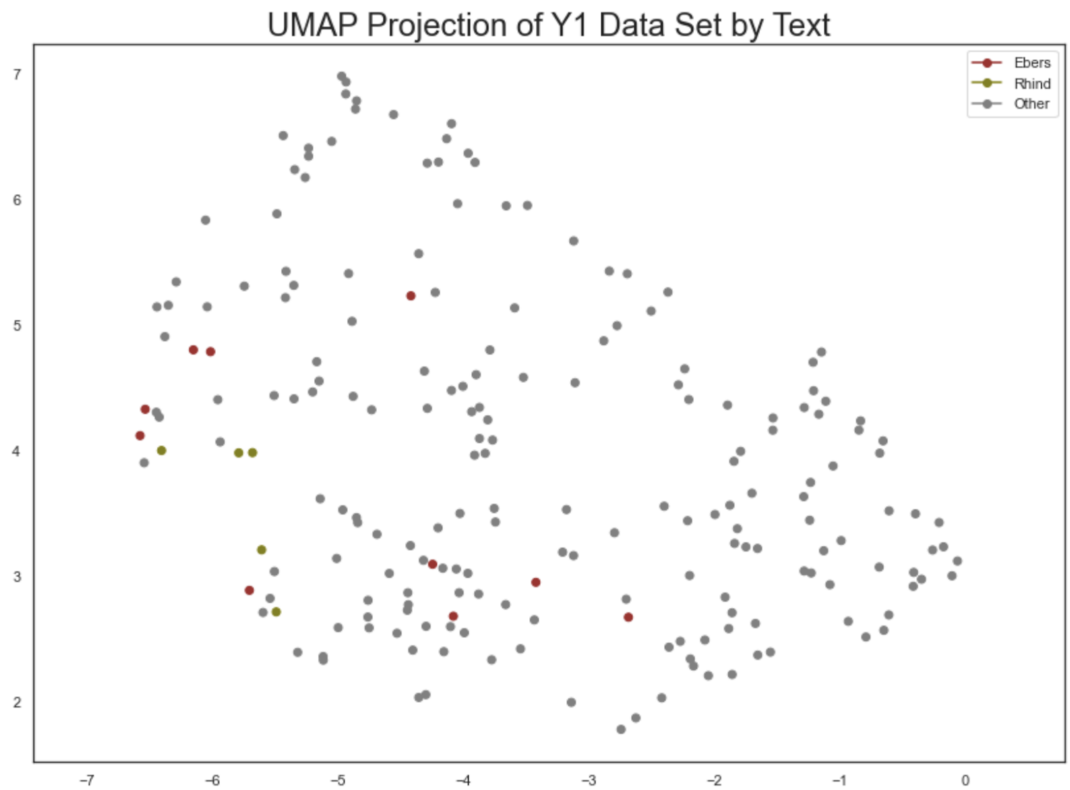

UMAP Projection of X1 Data Set by Text
Ebers
Rhind
Other
7
6
5
4
3
2
1
0
0
2
4
6
8
10

Figure 30


UMAP Projection of Y1 Data Set by Text
Ebers
Rhind
Other
7
6
5
4
3
2
−7
−6
−5
−4
−3
−2
−1
0

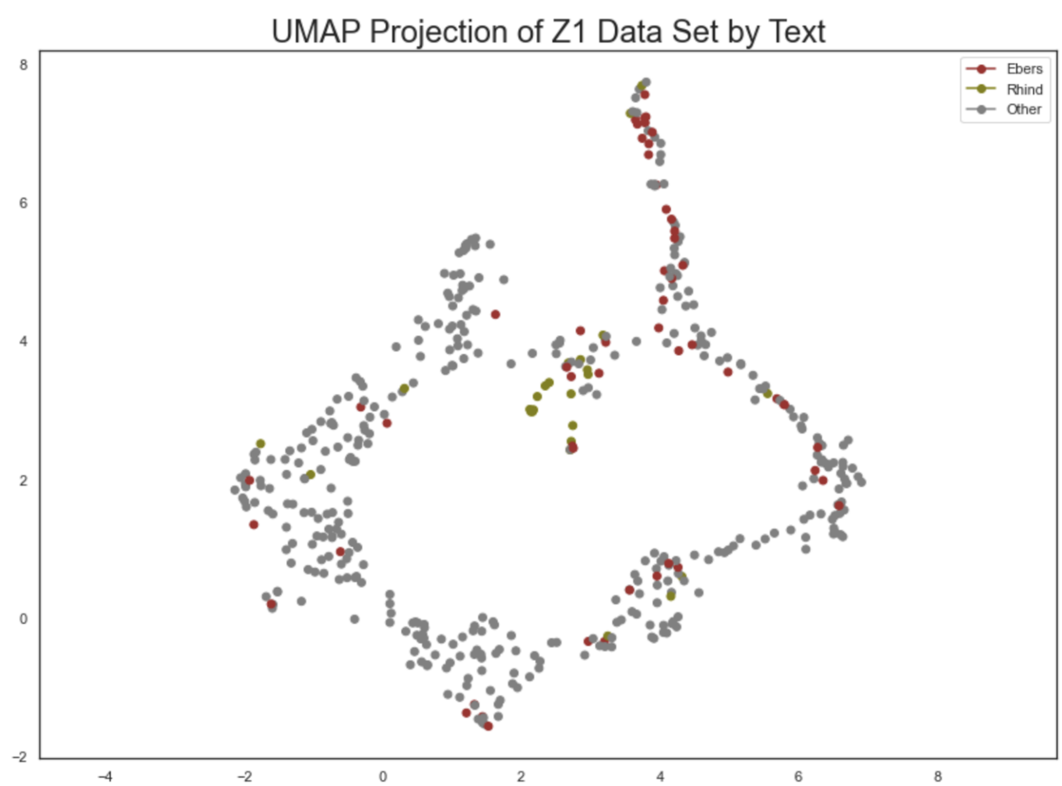
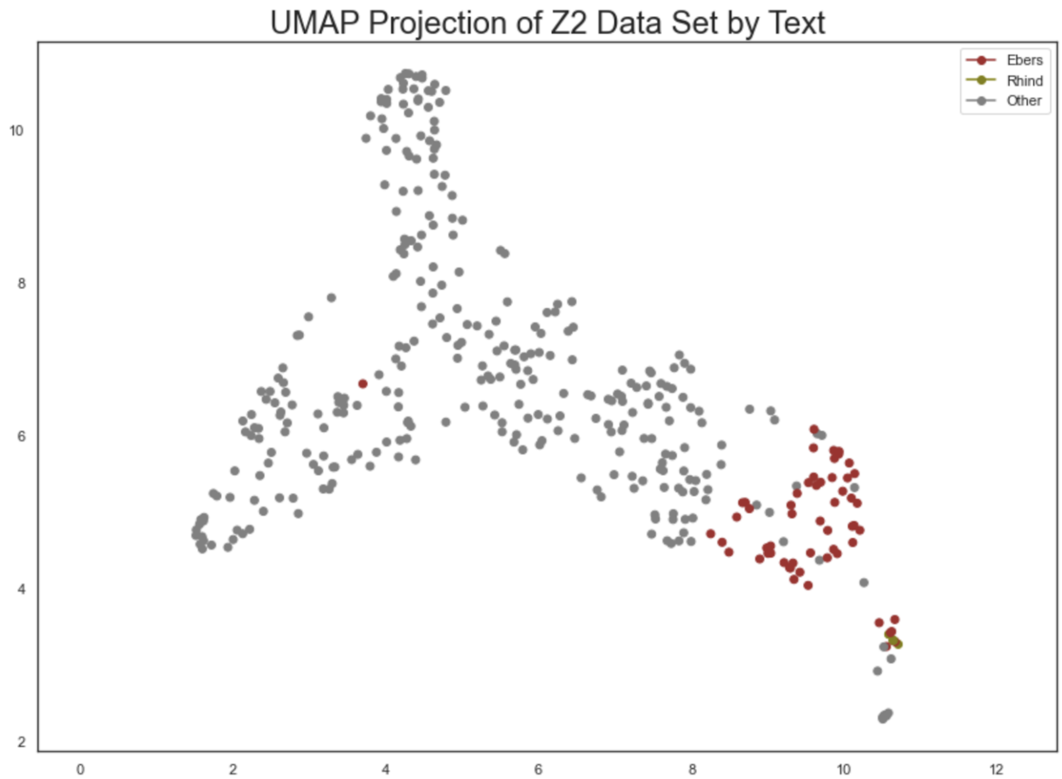

UMAP Projection of Z1 Data Set by Text
Ebers
Rhind
Other
8
6
4
2
0
−2
−4
−2
0
2
4
6
8

Figure 30

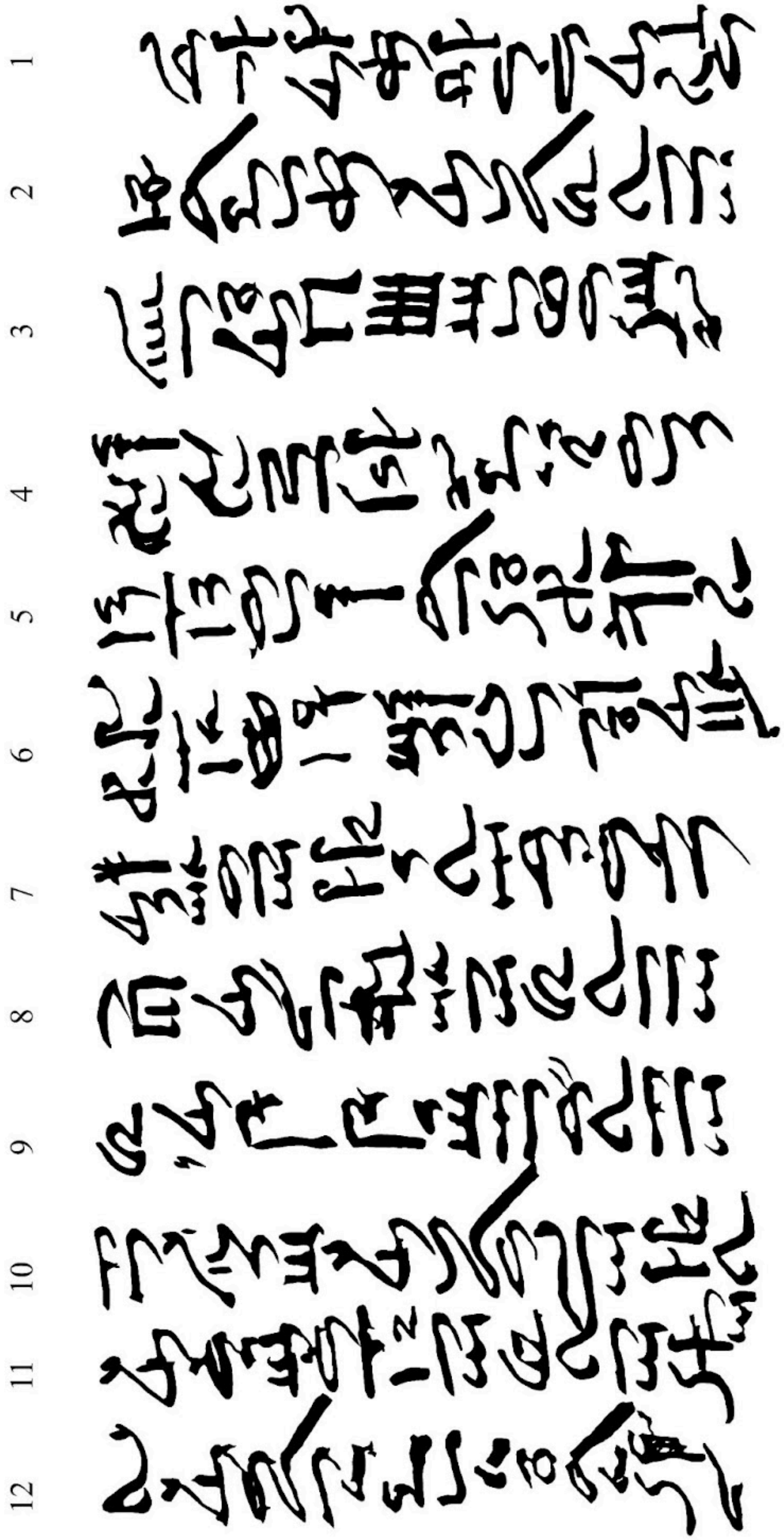


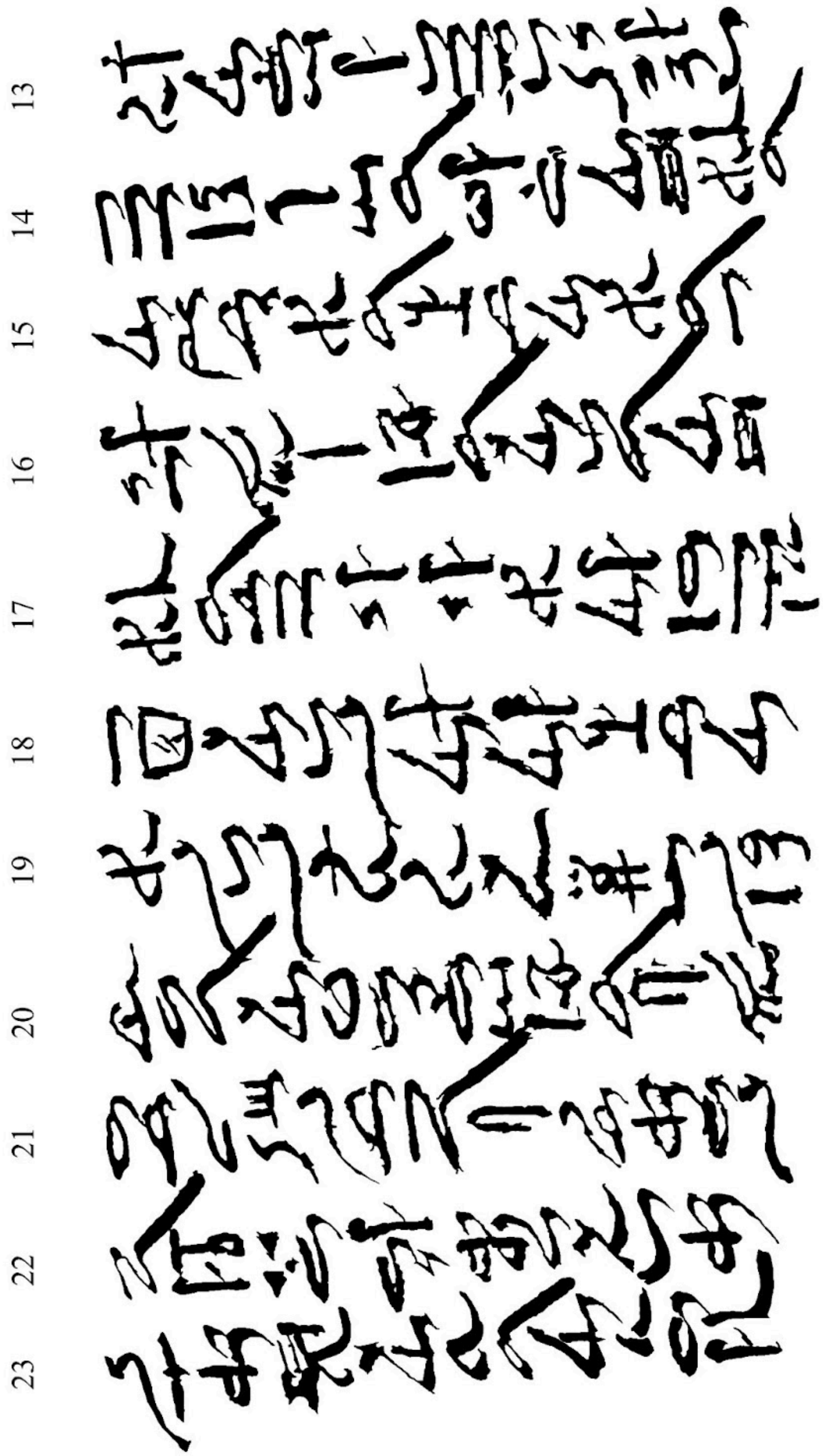
UMAP Projection of Z2 Data Set by Text
Ebers
Rhind
Other
10
8
6
4
2
0
2
4
6
8
10
12

Appendix 2: Tabin Facsimiles

Here, the facsimiles created specifically for this project are presented. The facsimiles were made according to the "Methods" section of this work. The first sixteen pages (pg. 143-158) are the facsimile of P. Hermitage 1115 (The Shipwrecked Sailor), lines 1-189. The second sixteen pages (pg. 159-174) are the same facsimile, but with the damaged sections marked in red. The last five pages (pg. 175-179) are the facsimile of P. Berlin 3023 (Eloquent Peasant B1), lines 32-121. In this last facsimile, red ink is indicated by hollow signs. There is no damage-marked version of P. Berlin 3023 due to the time constraints on this work.

One should notice that there may be small errors with these facsimiles in places. Although they were each created twice and checked many times over, there are still places with minor errors, such as some pixels not being filled in. However, this did not impact this work, because, during the annotation step, the facsimiles were checked for imperfections. The individual signs were also checked multiple times after each one was cut out of the facsimiles. Thus, the final signs used for the program are even more morphologically accurate and pristine than those present in these images. Despite the rigorous quality control, there are surely some signs that have retained errors, but all of the significant ones are certainly eliminated.




13
14
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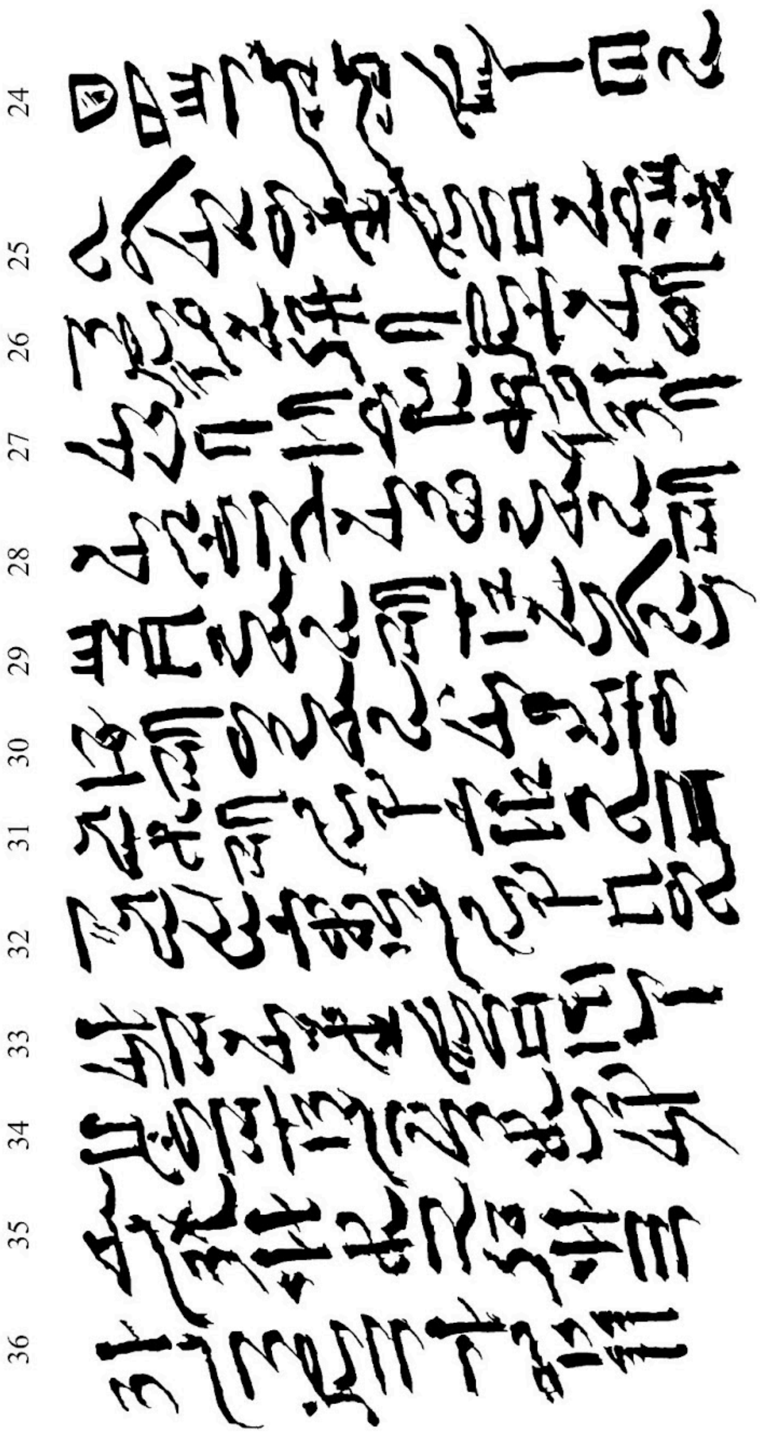
23


24
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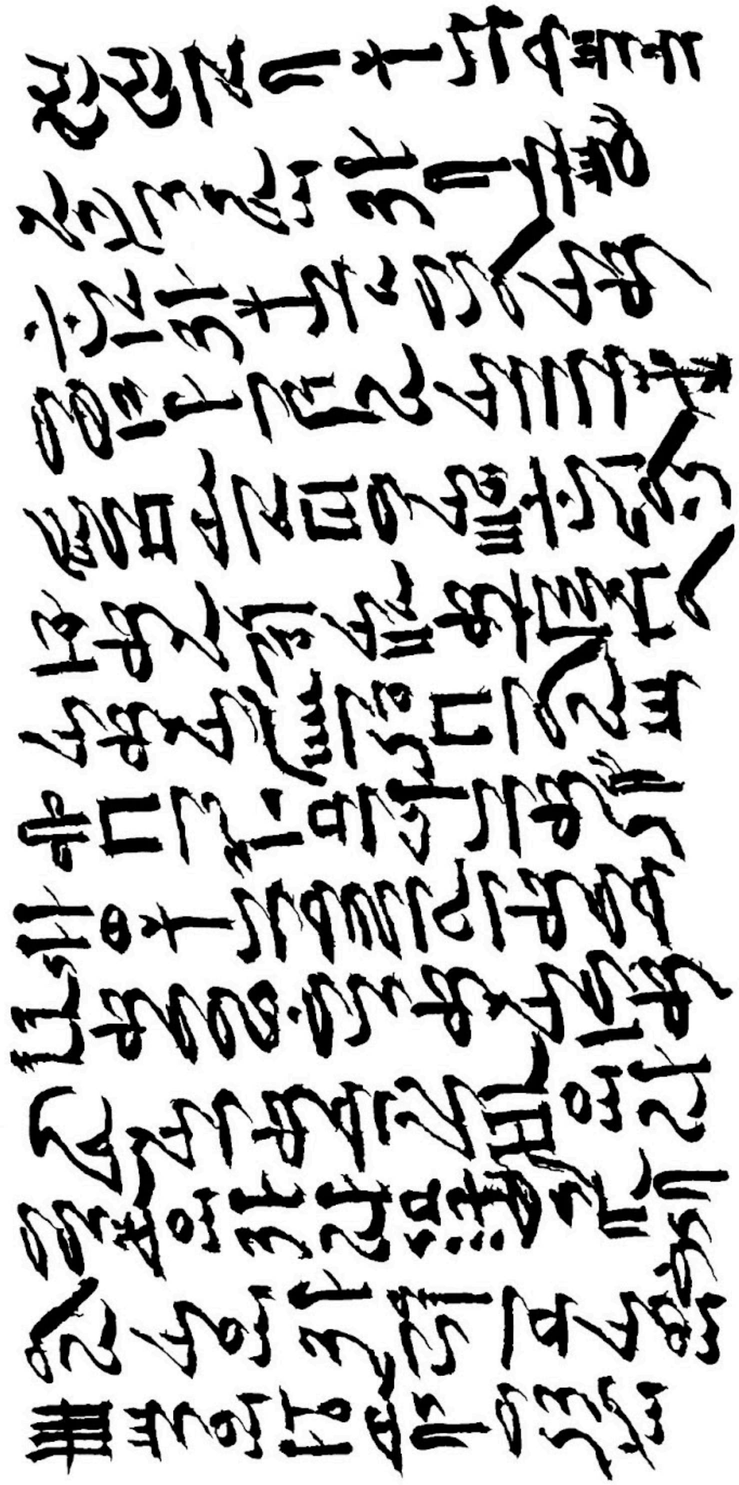
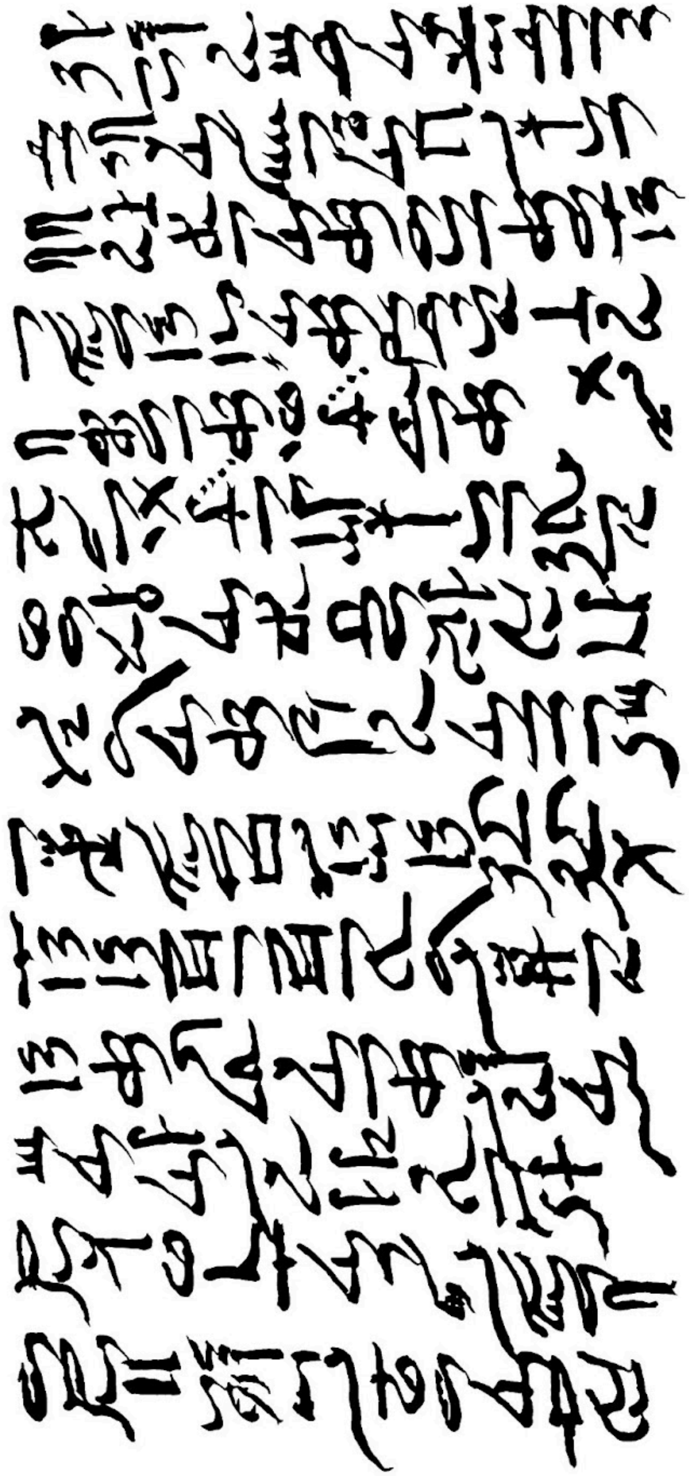
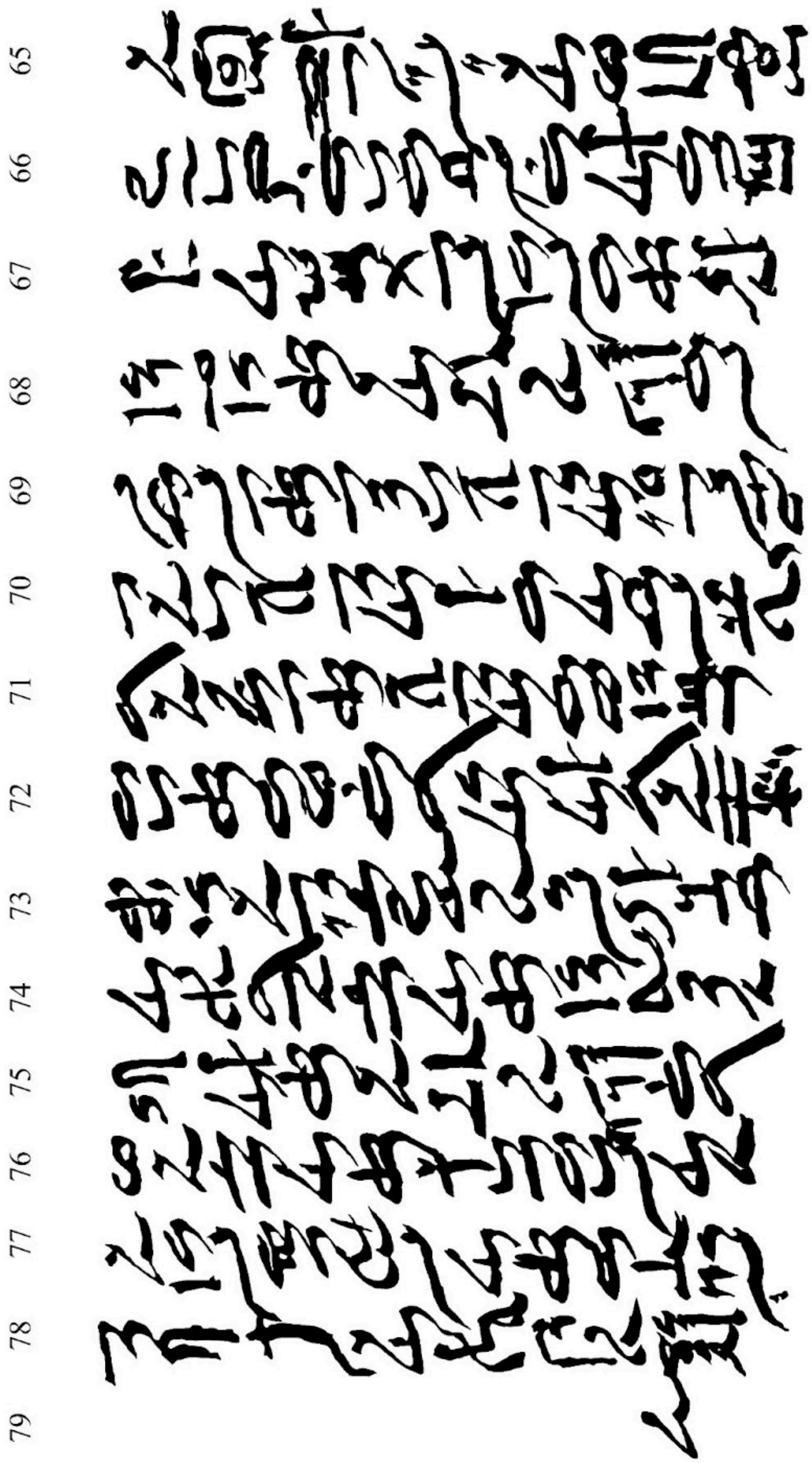
33
34
35
36






65
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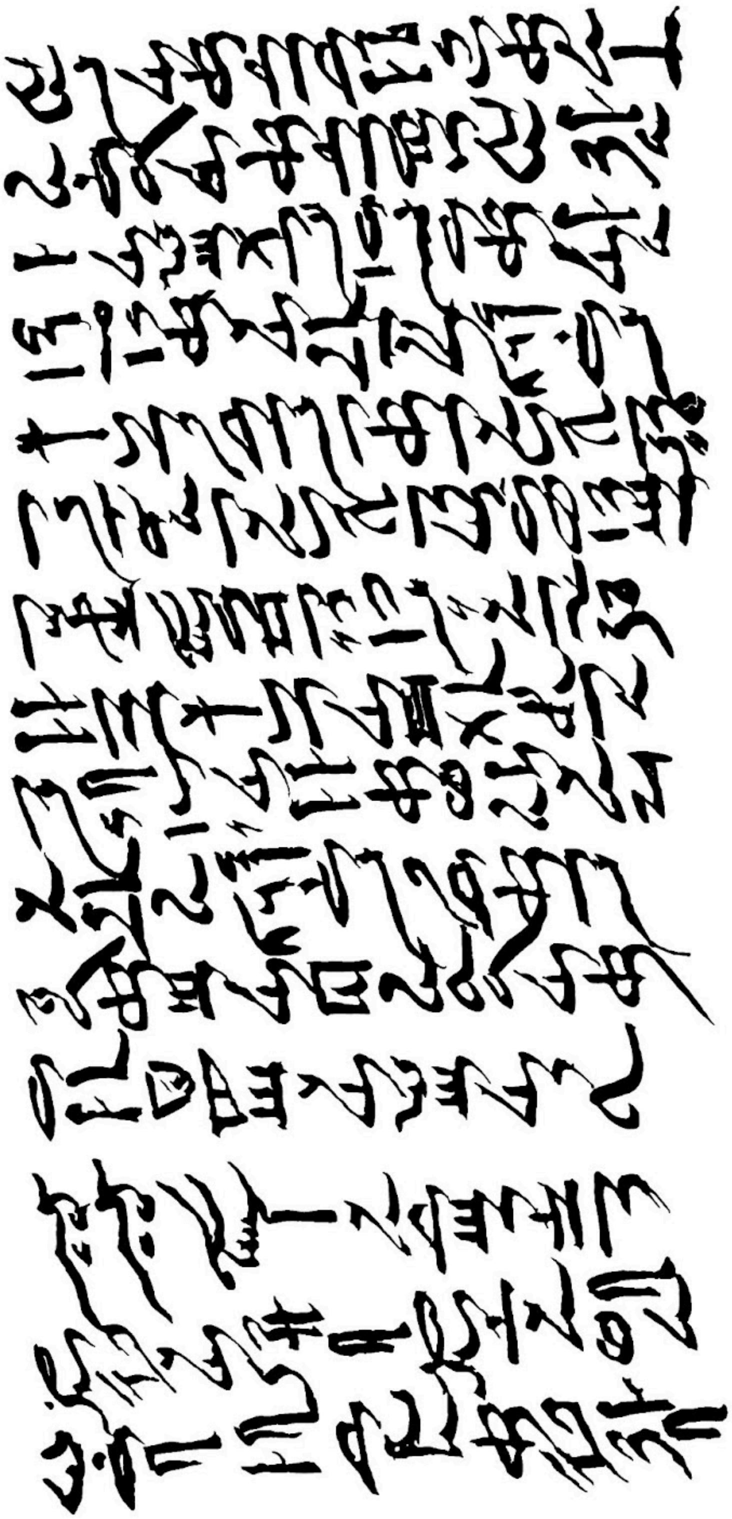
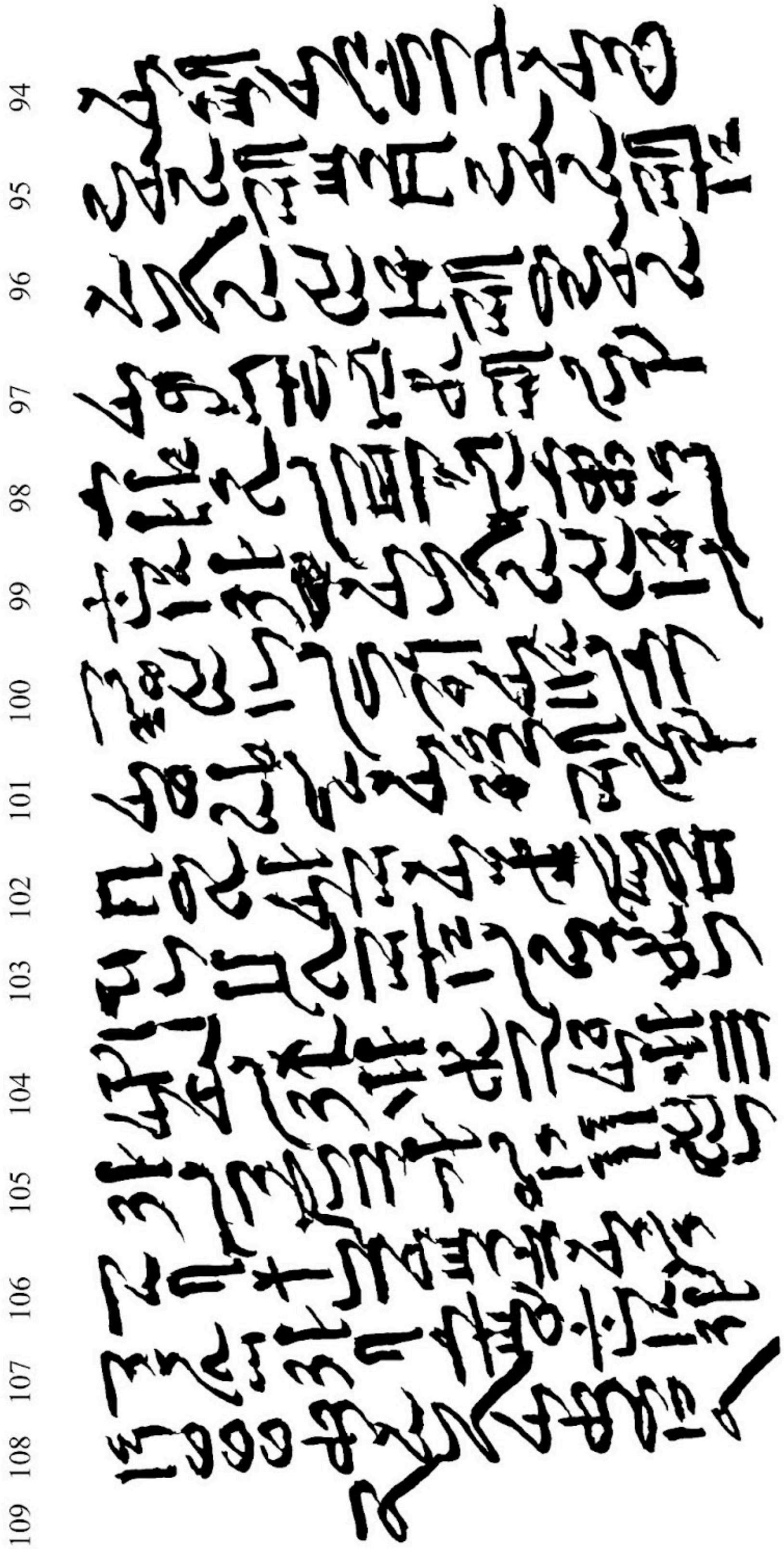
79




94
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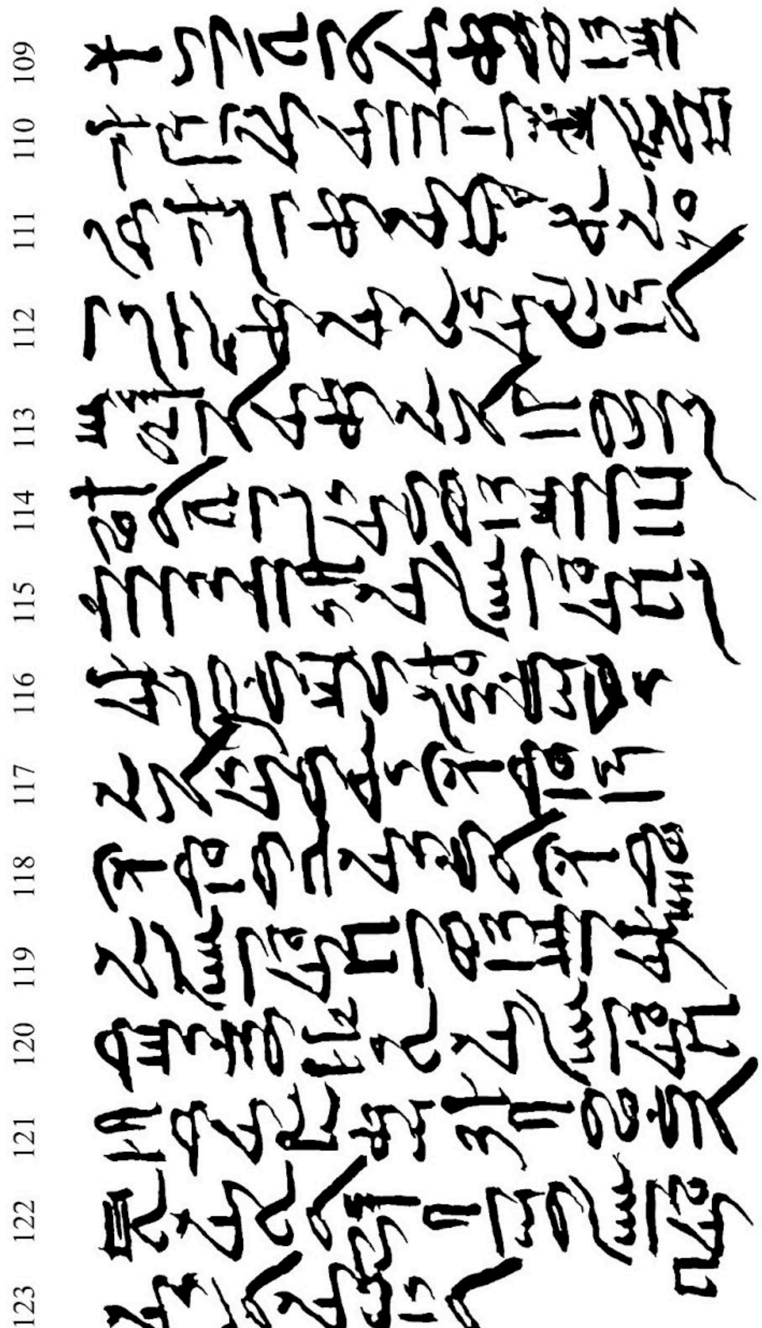
109


109
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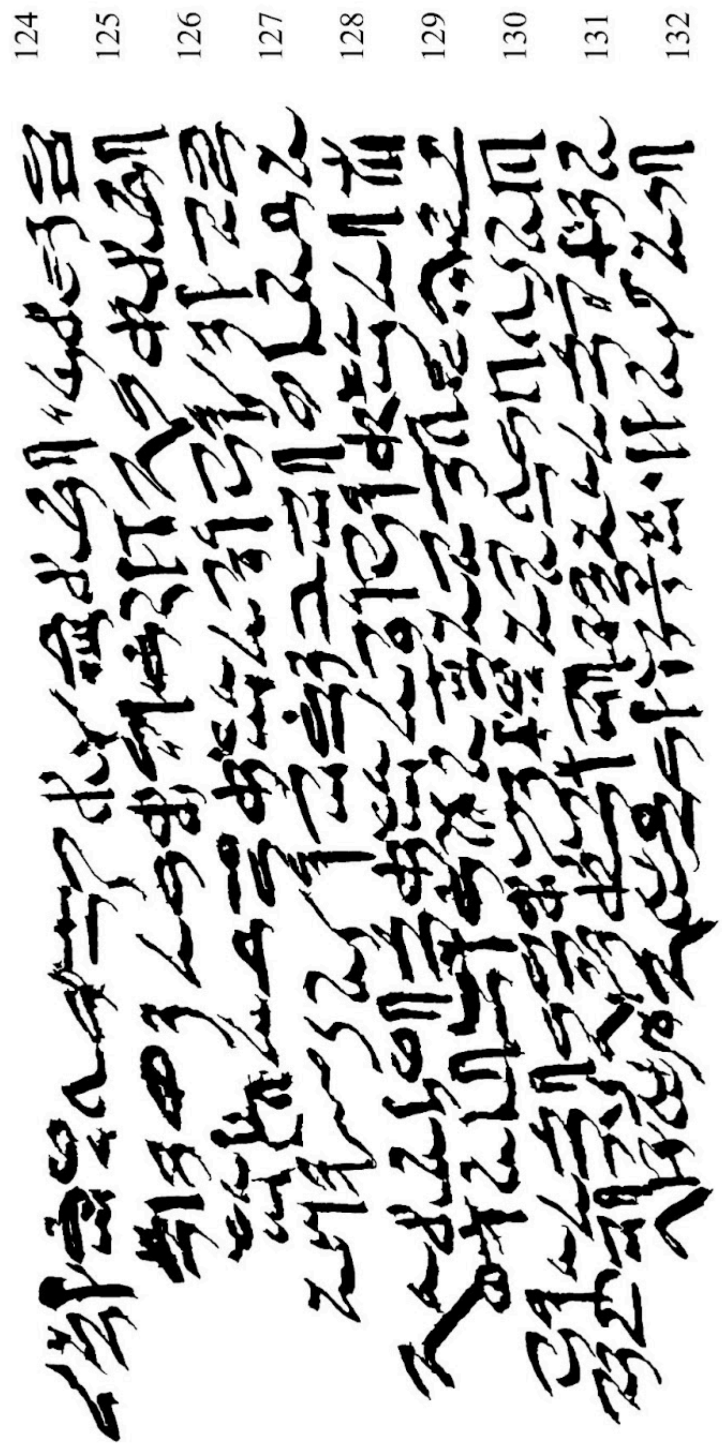
121
122
123




133
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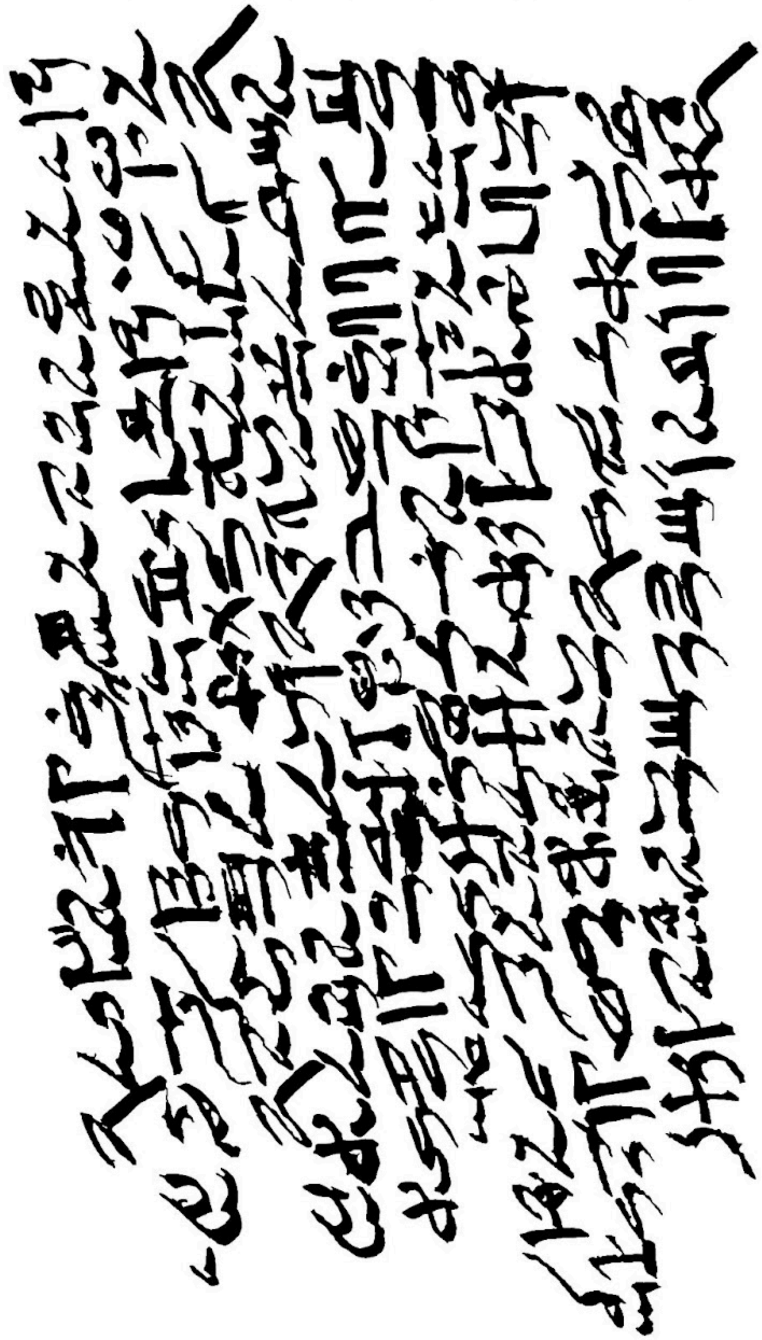
141
142




152
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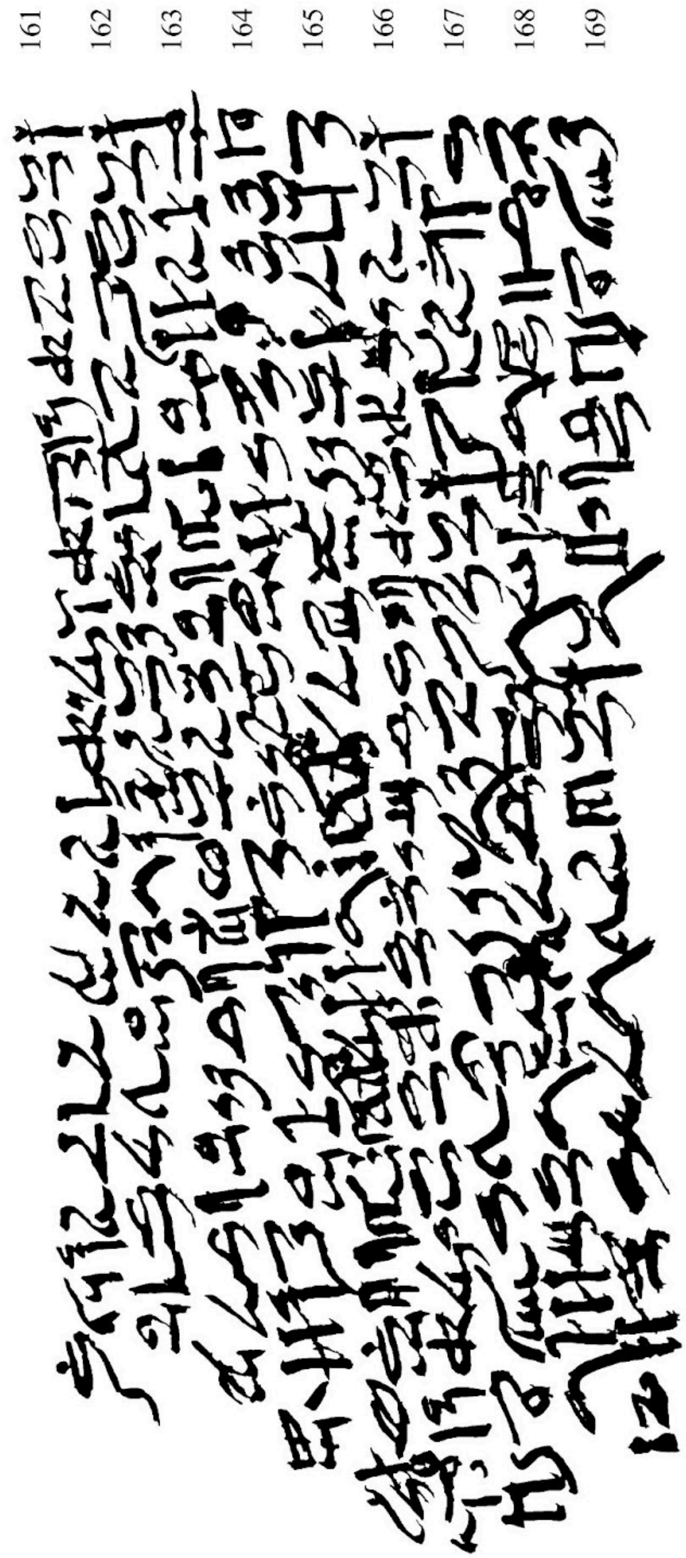
158
159
160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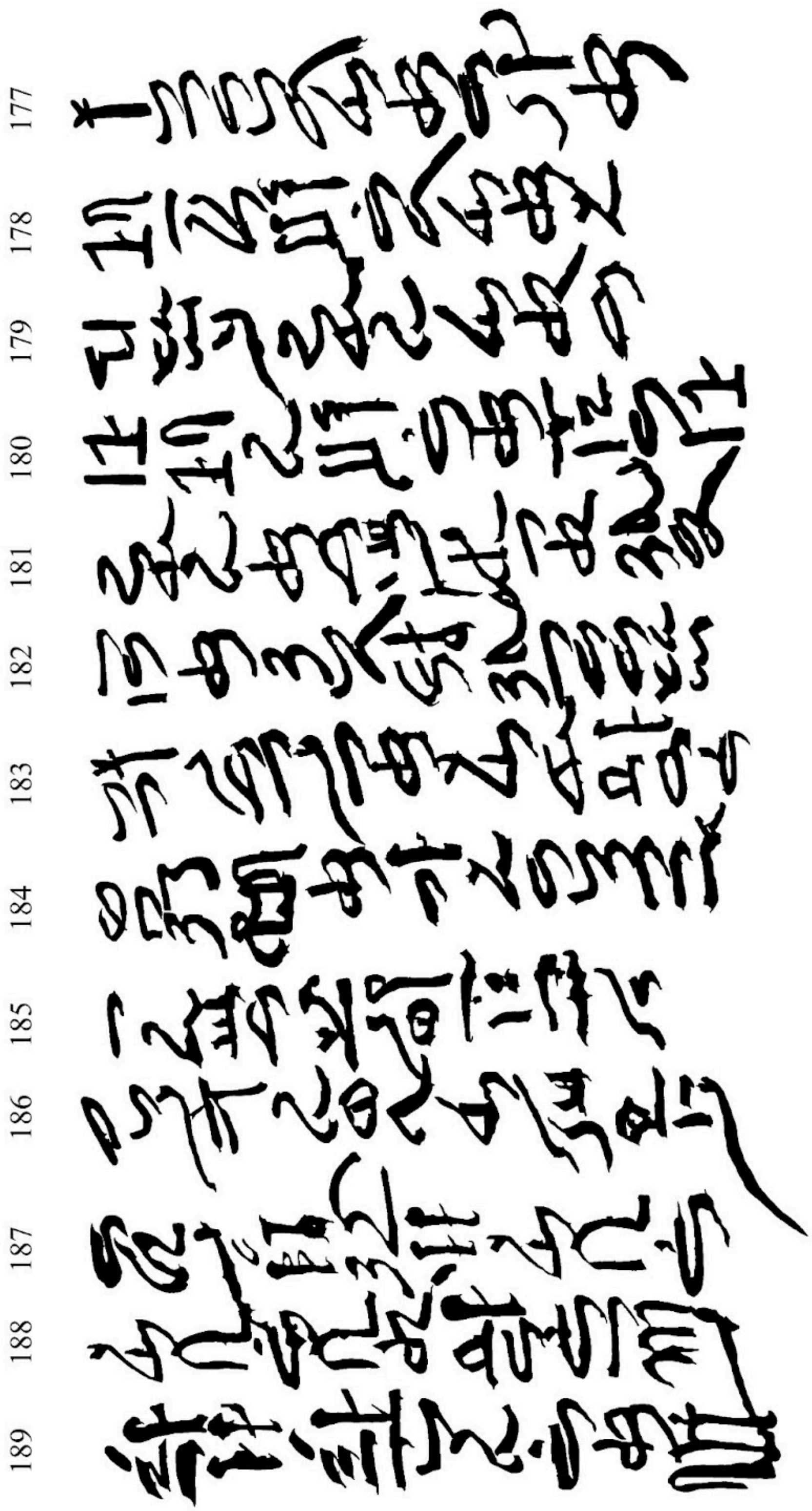
177
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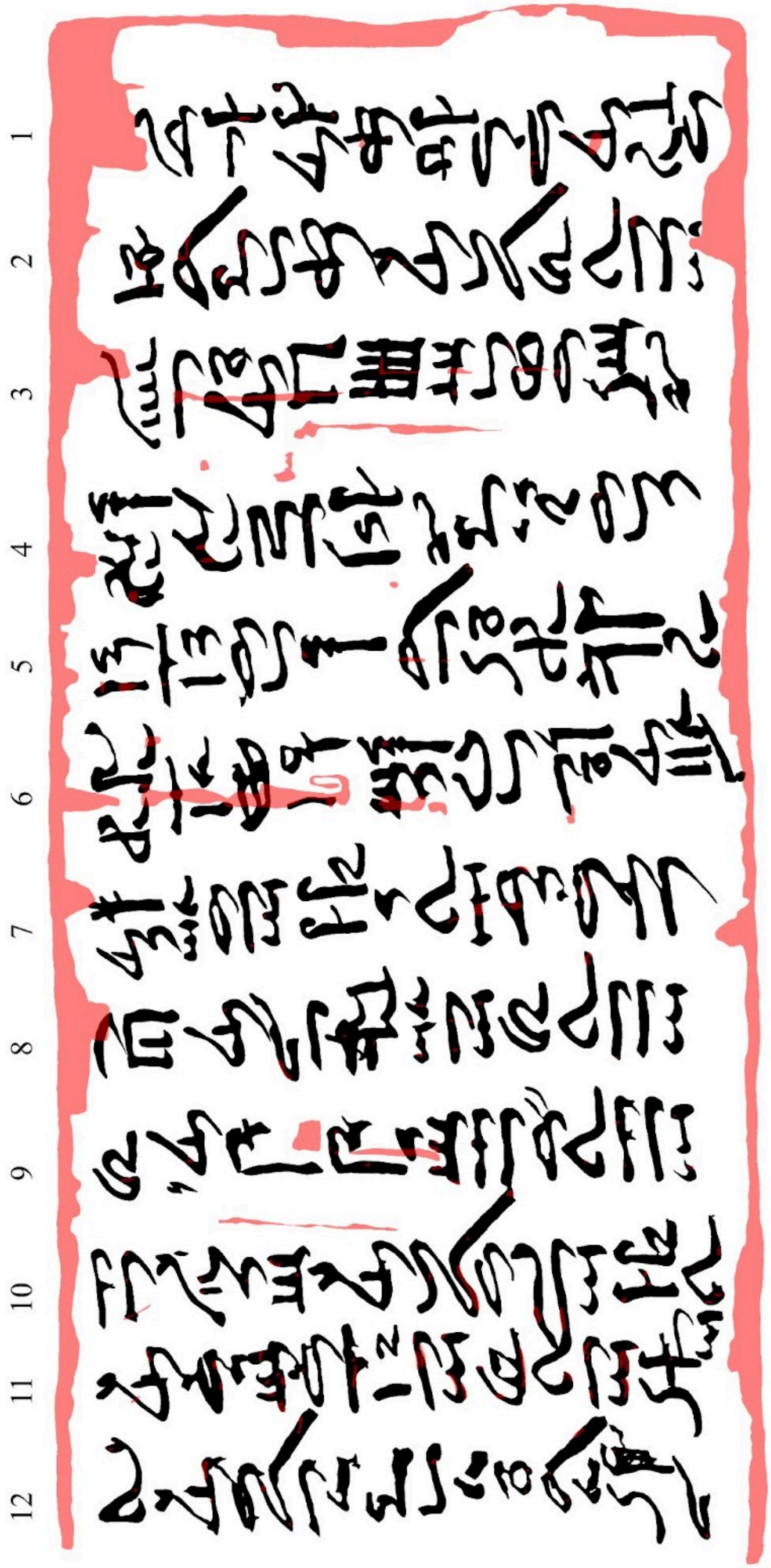
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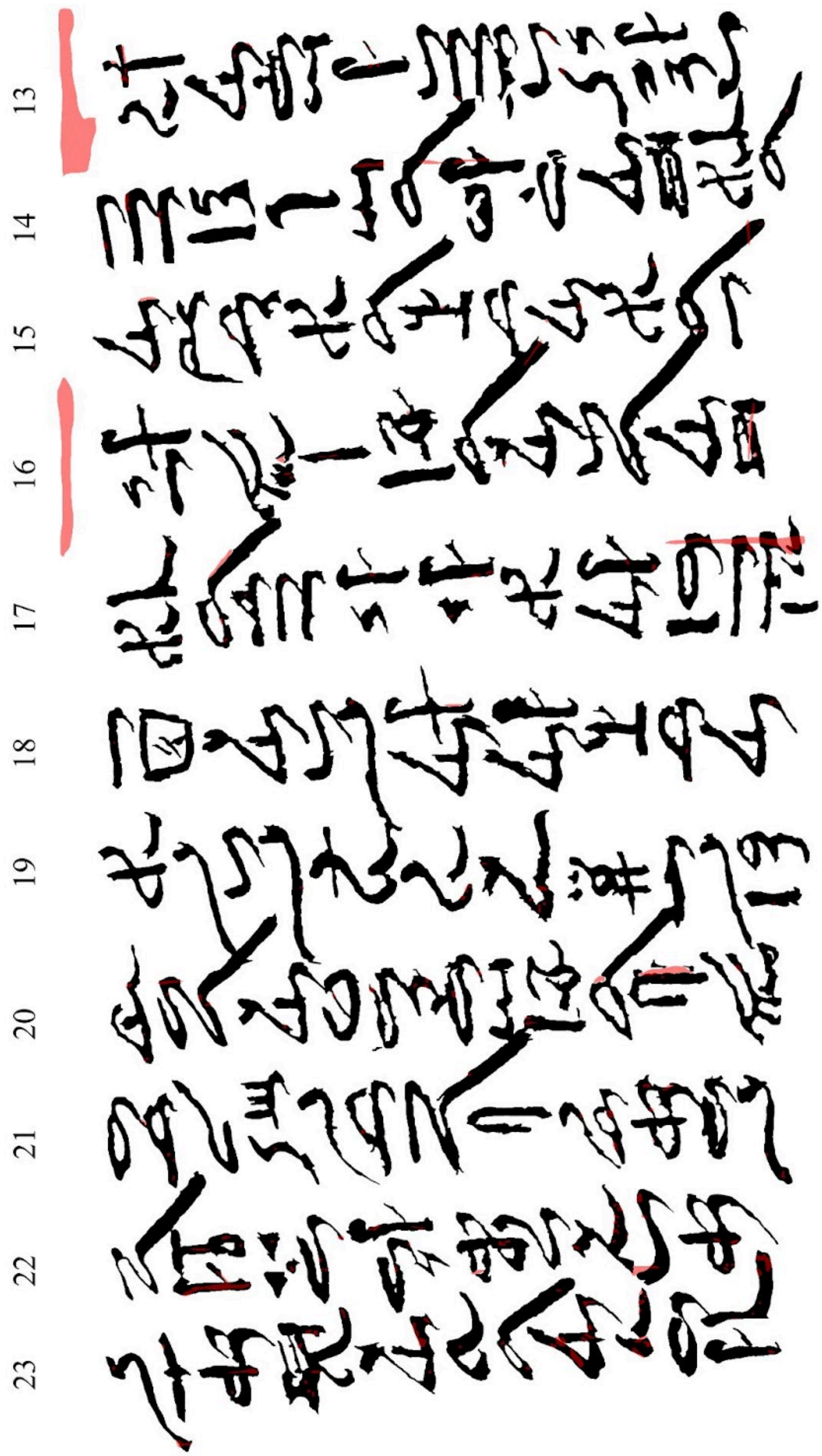

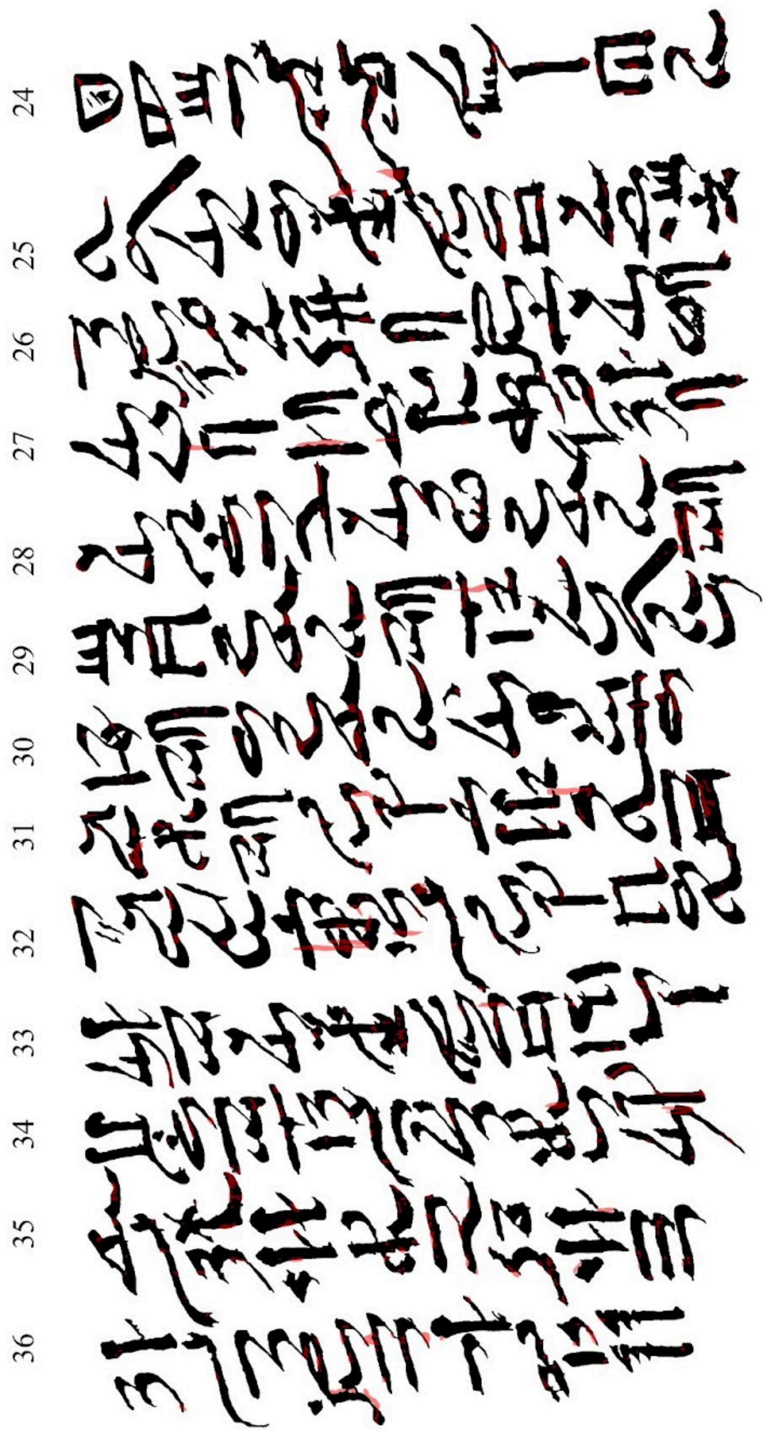
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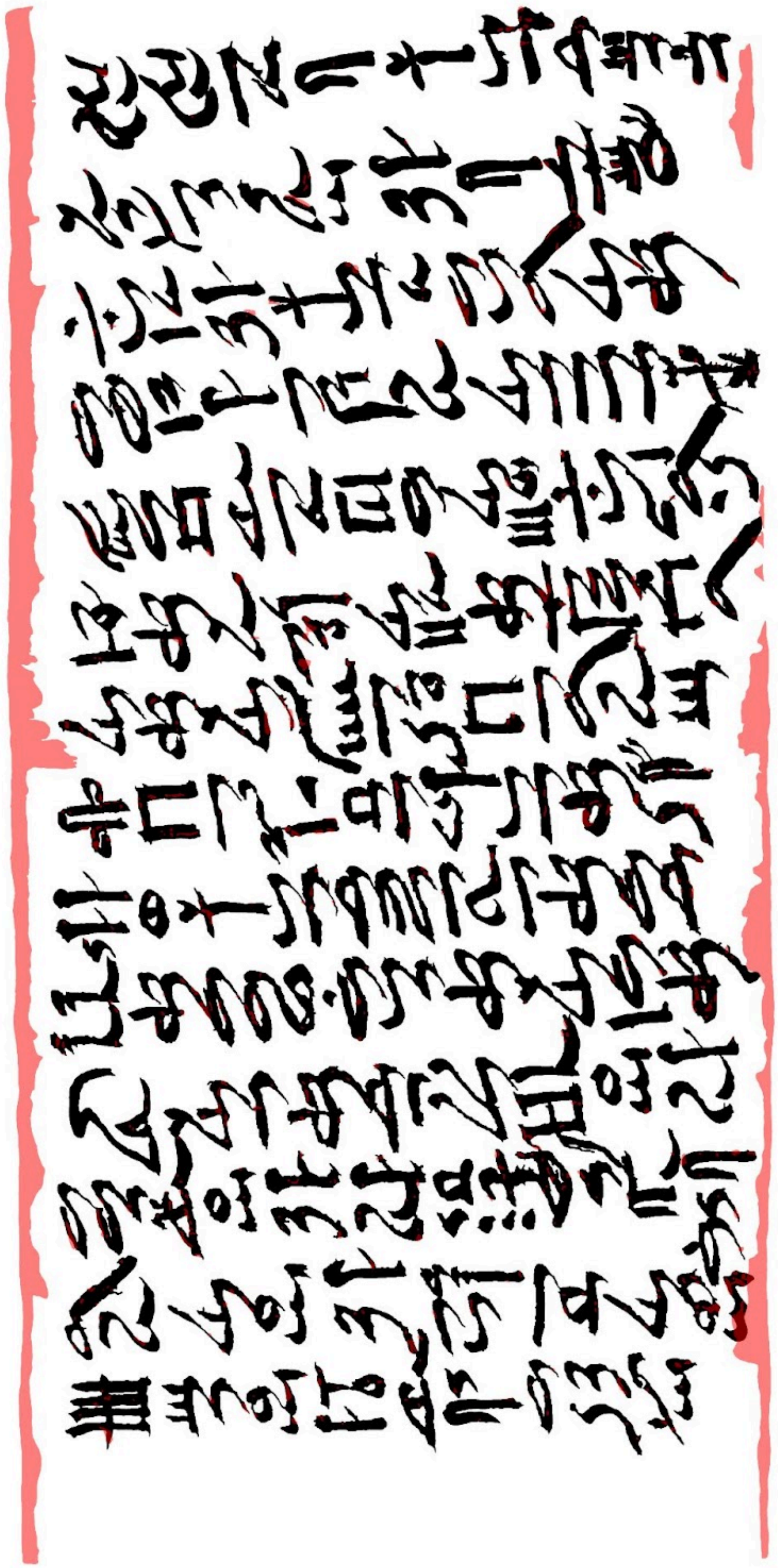

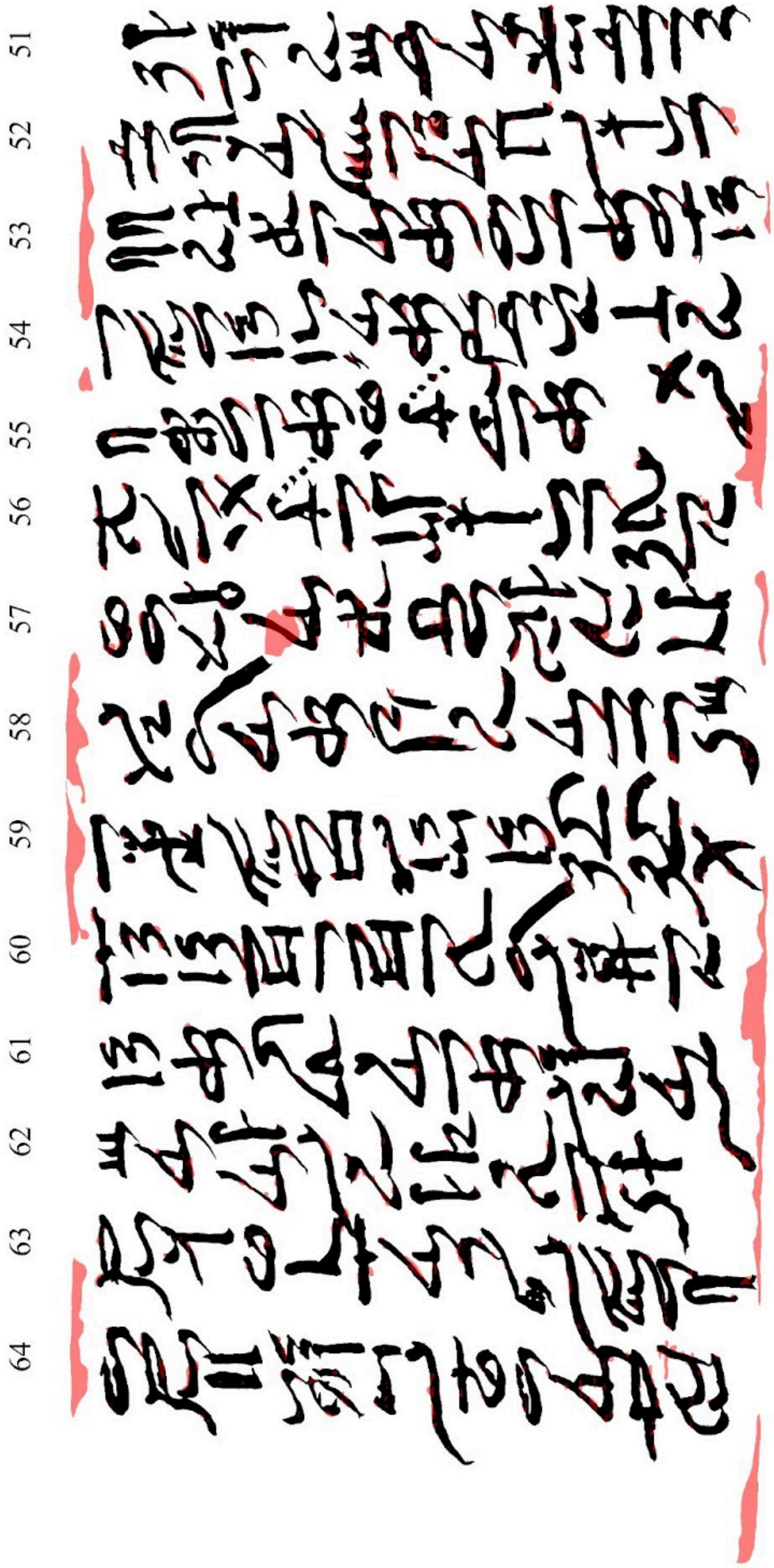
51
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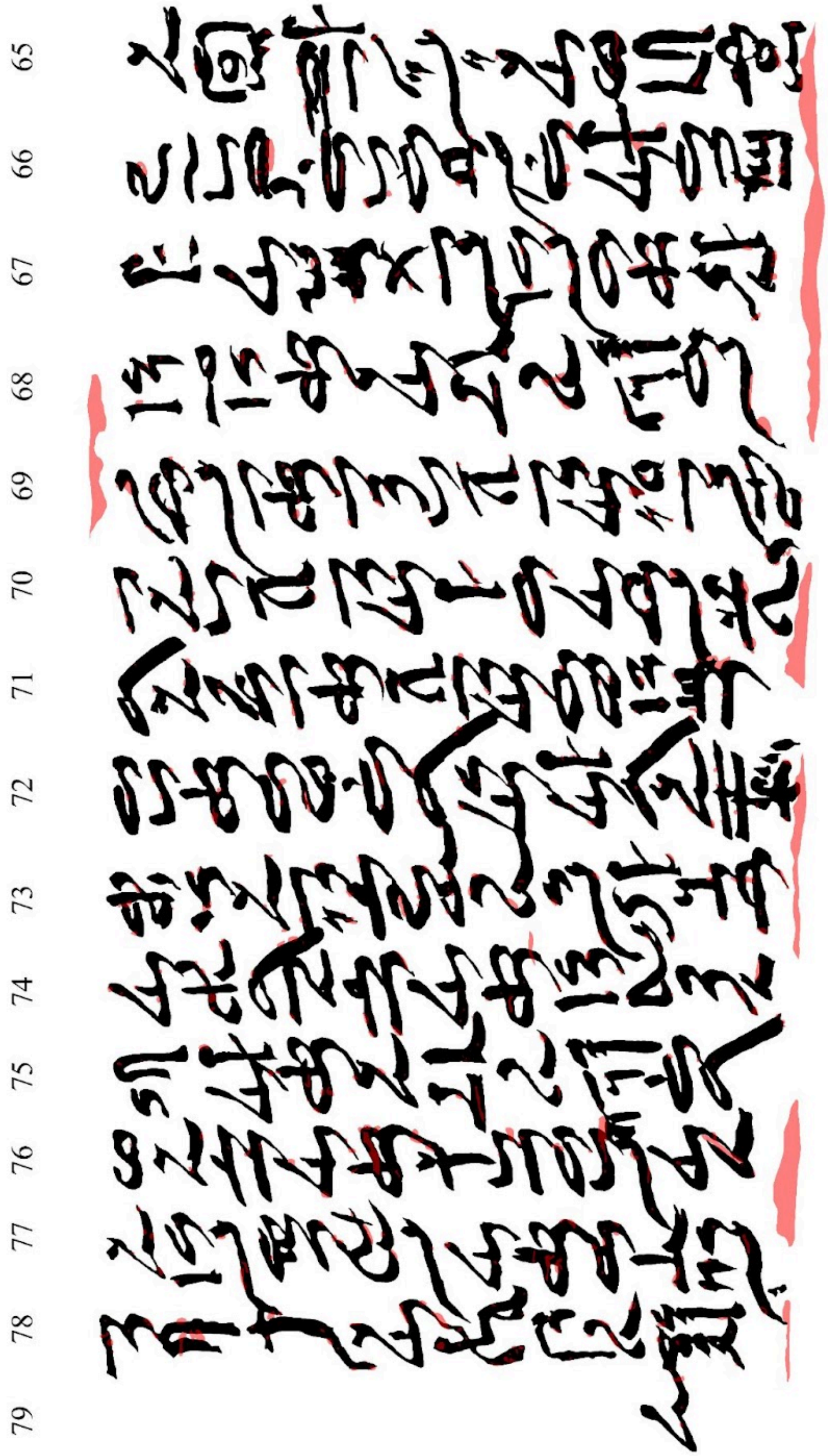
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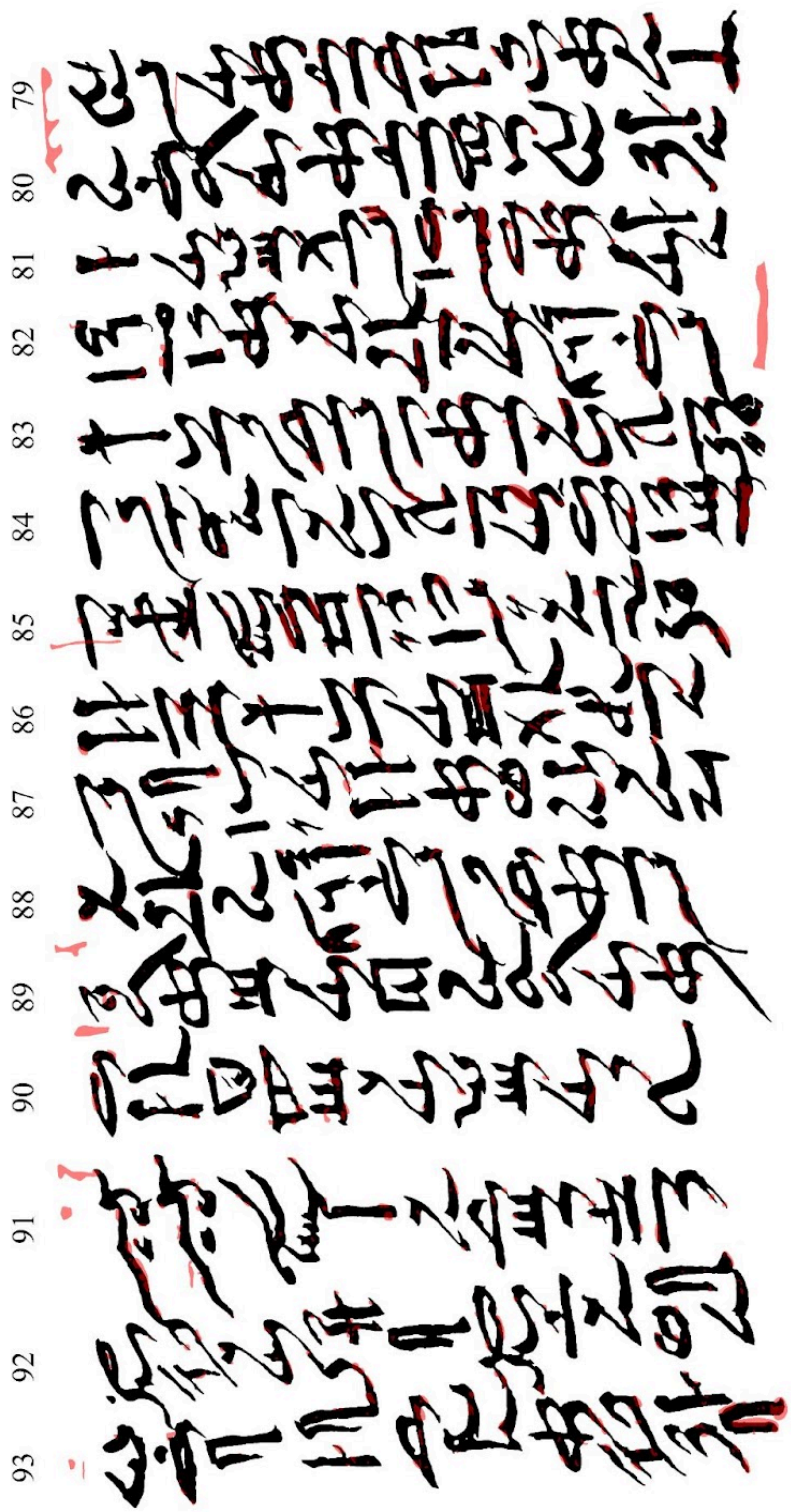
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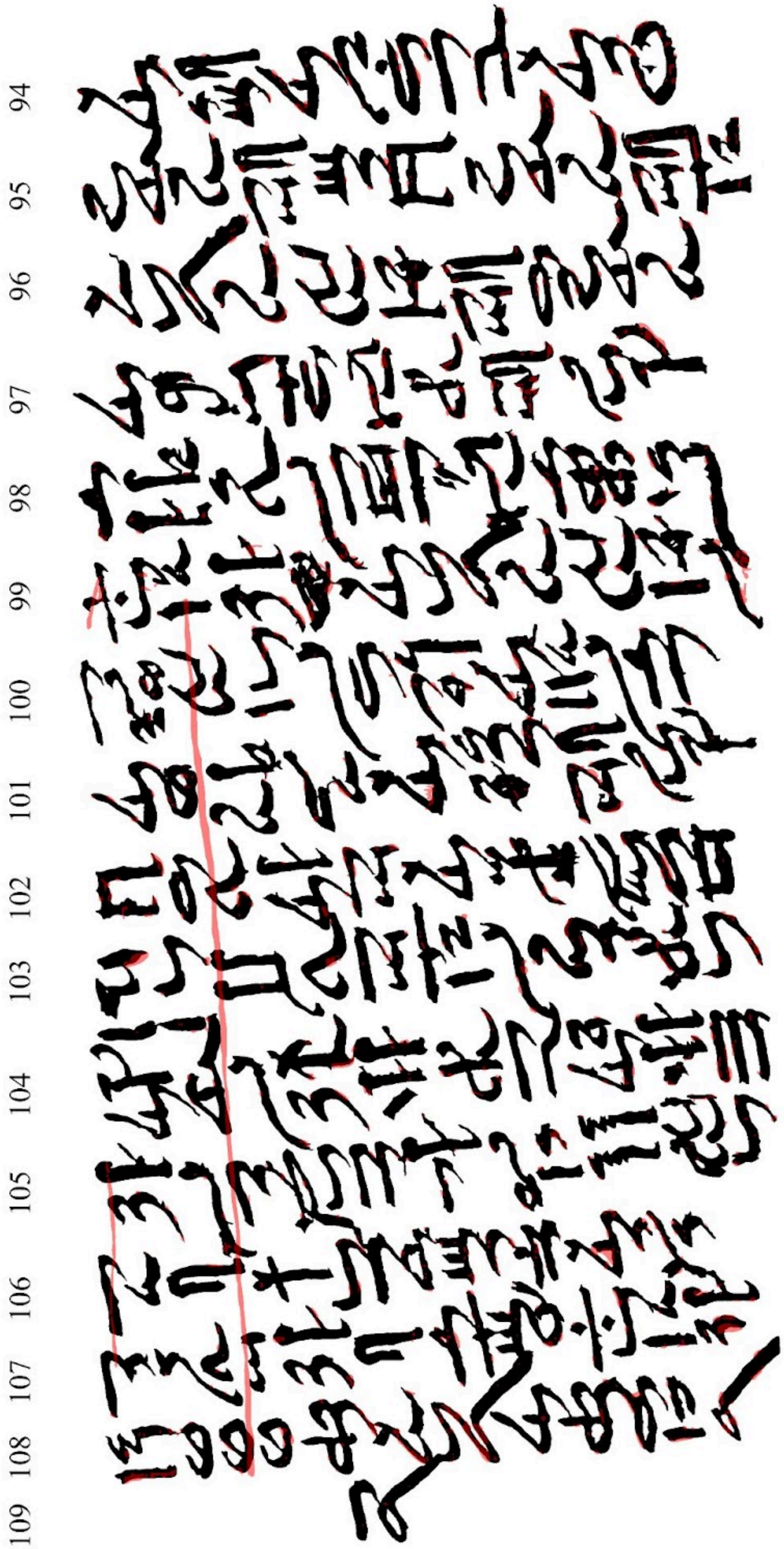
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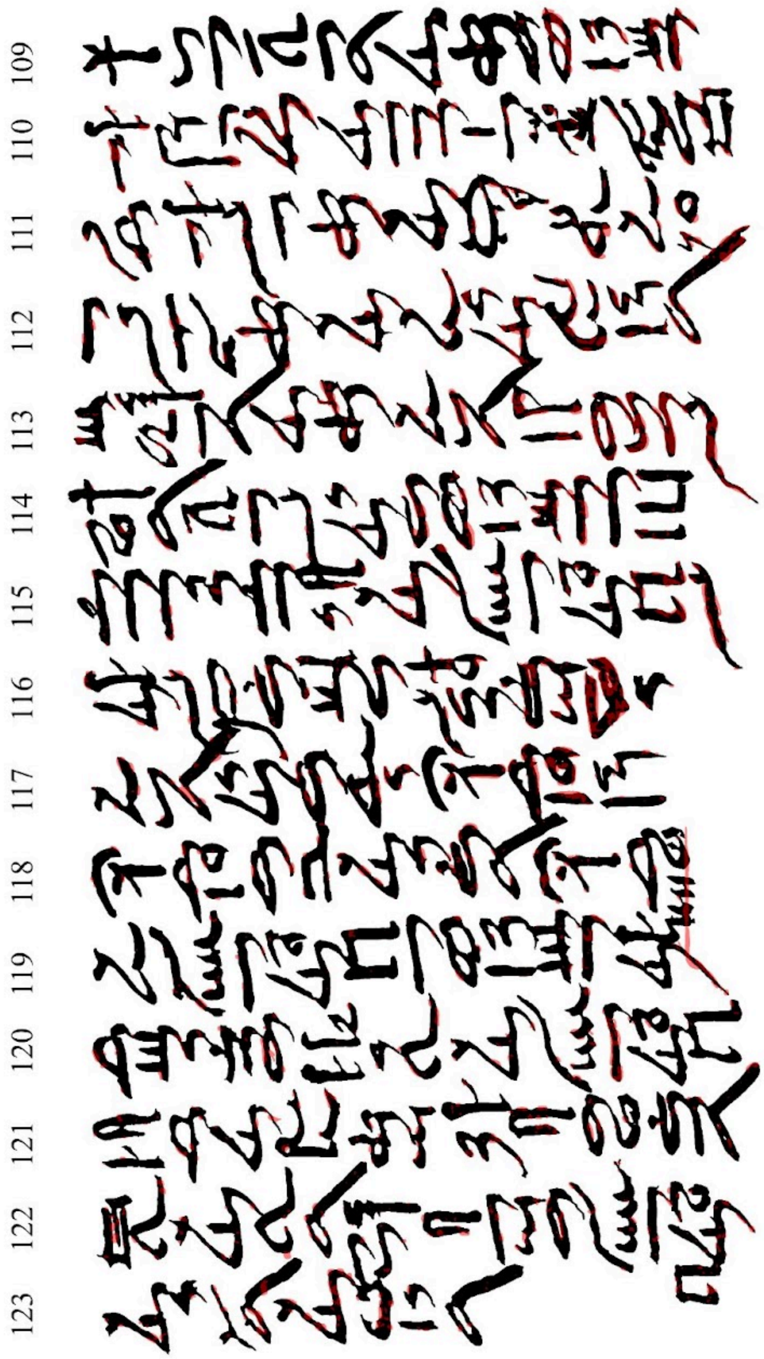
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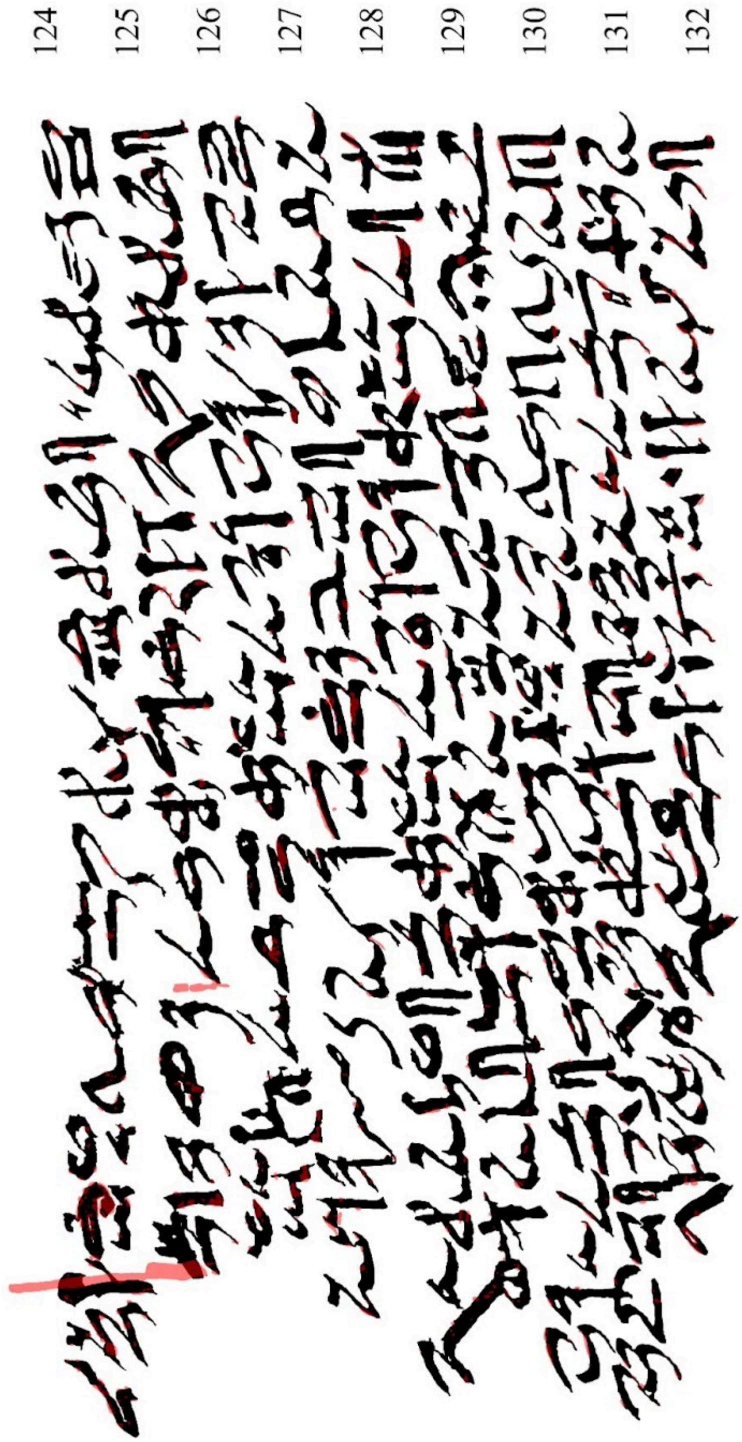
123




133
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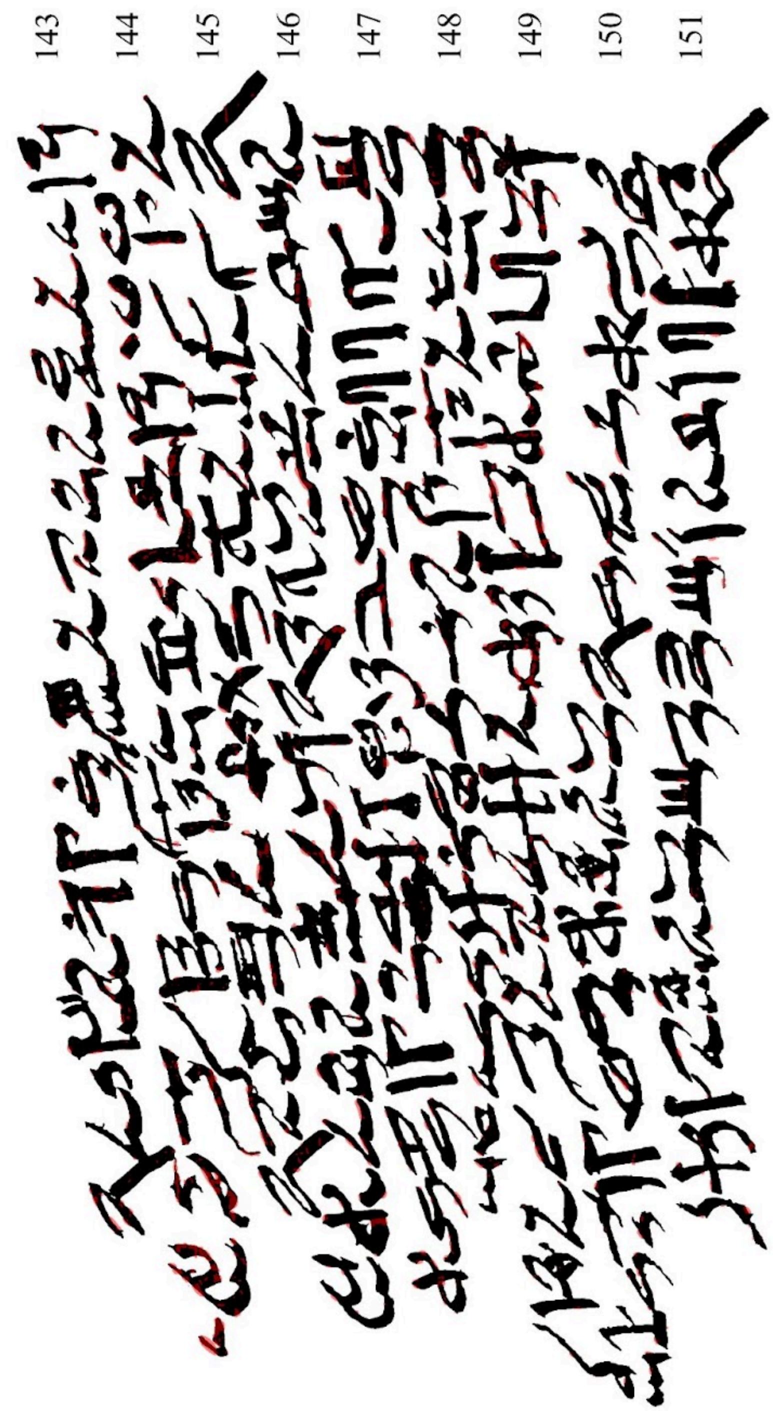
140
141
142


143
144
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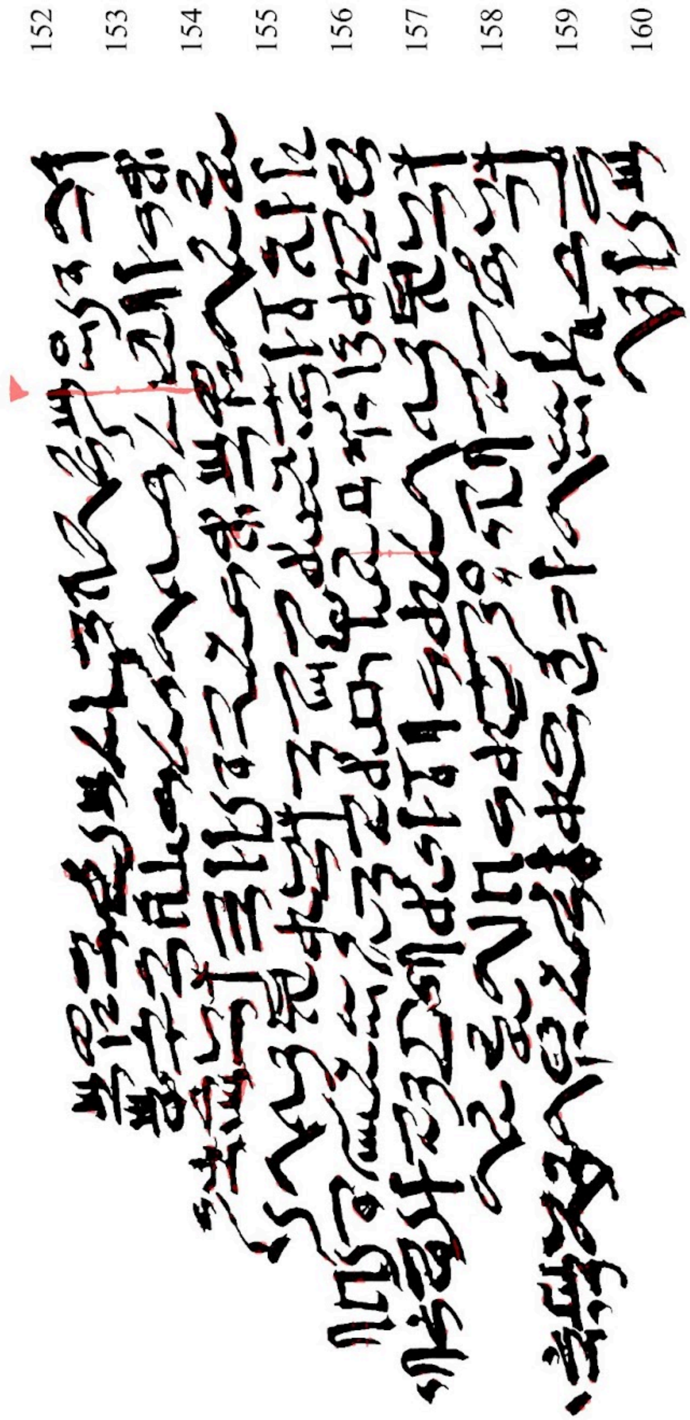
150
151


152
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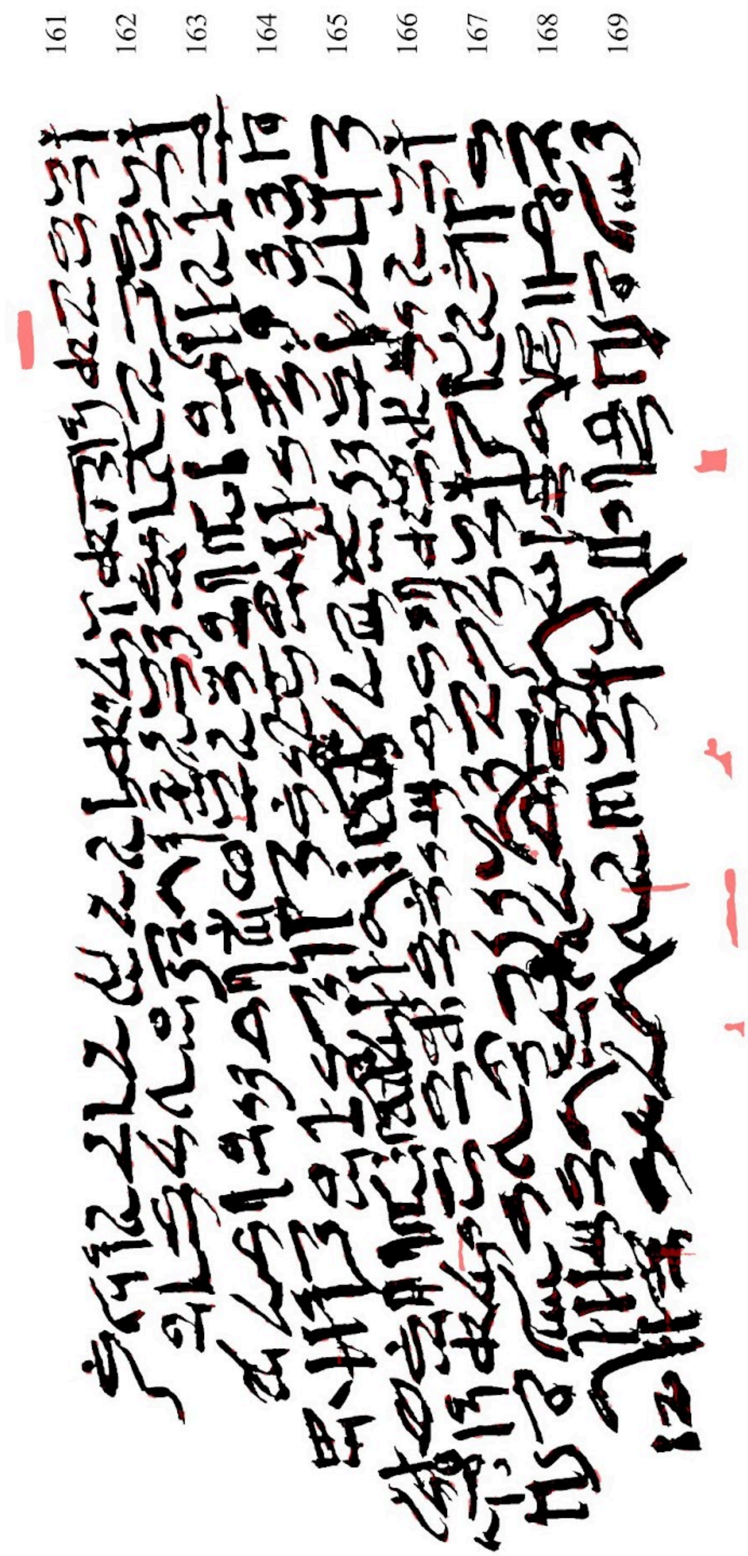
160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164
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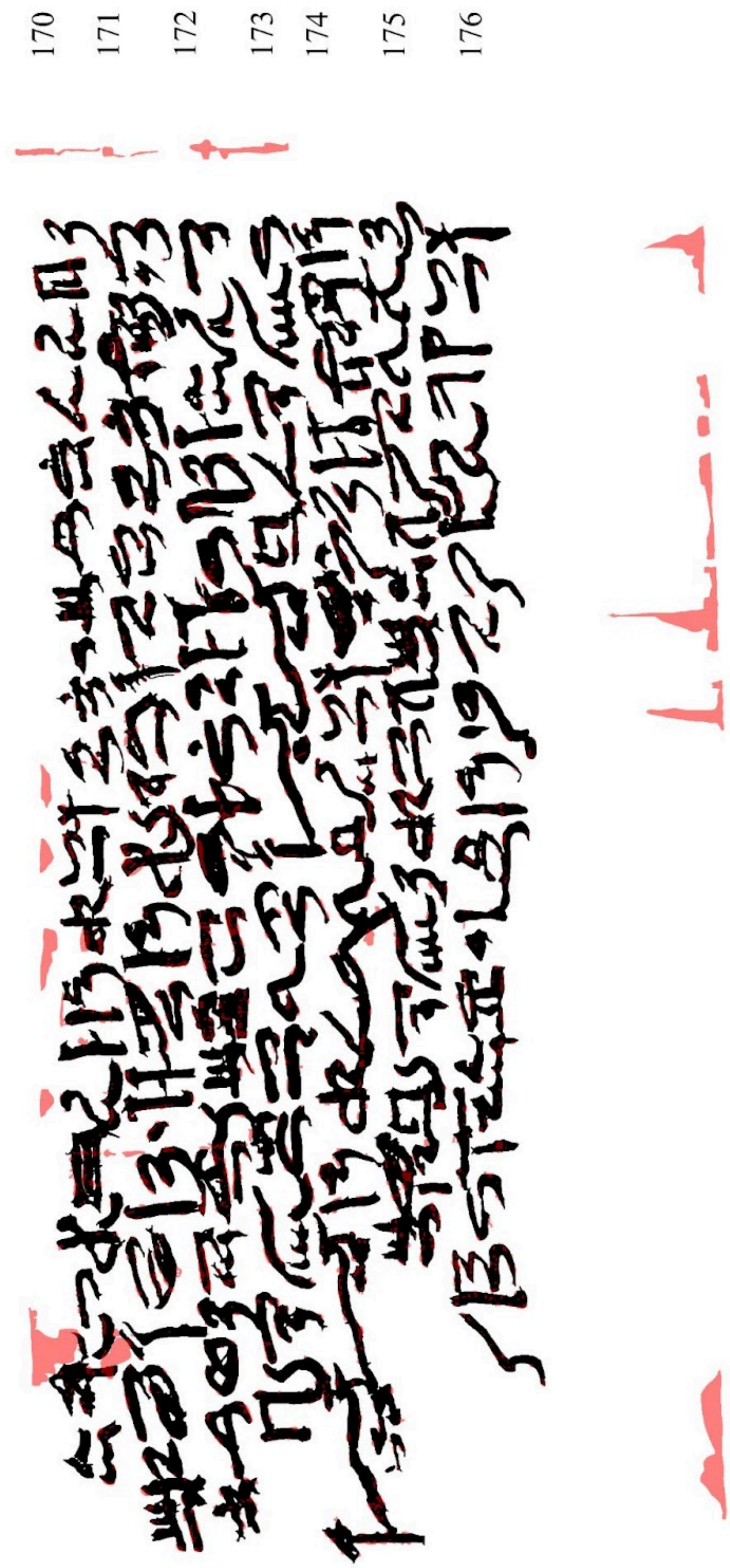
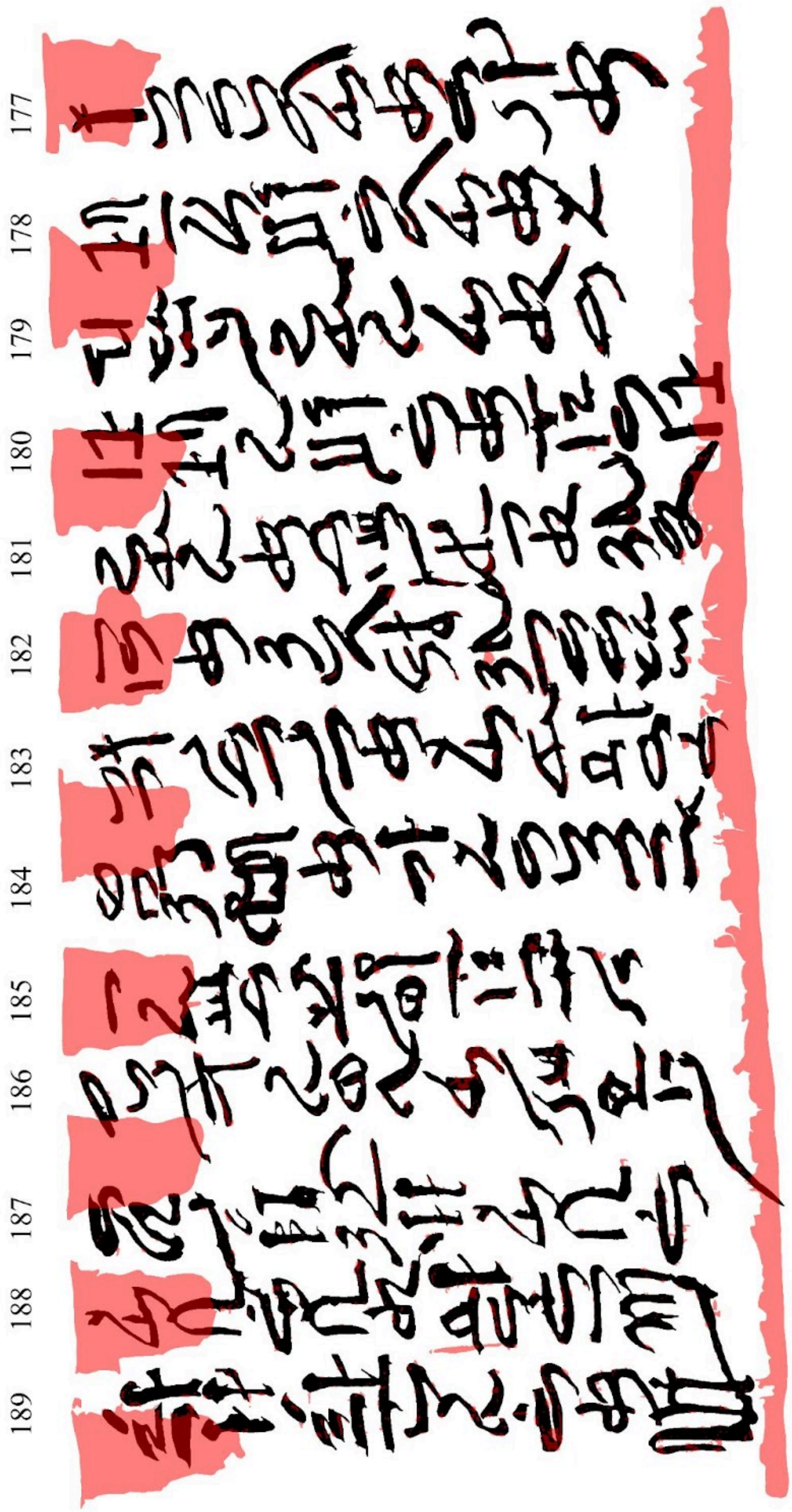
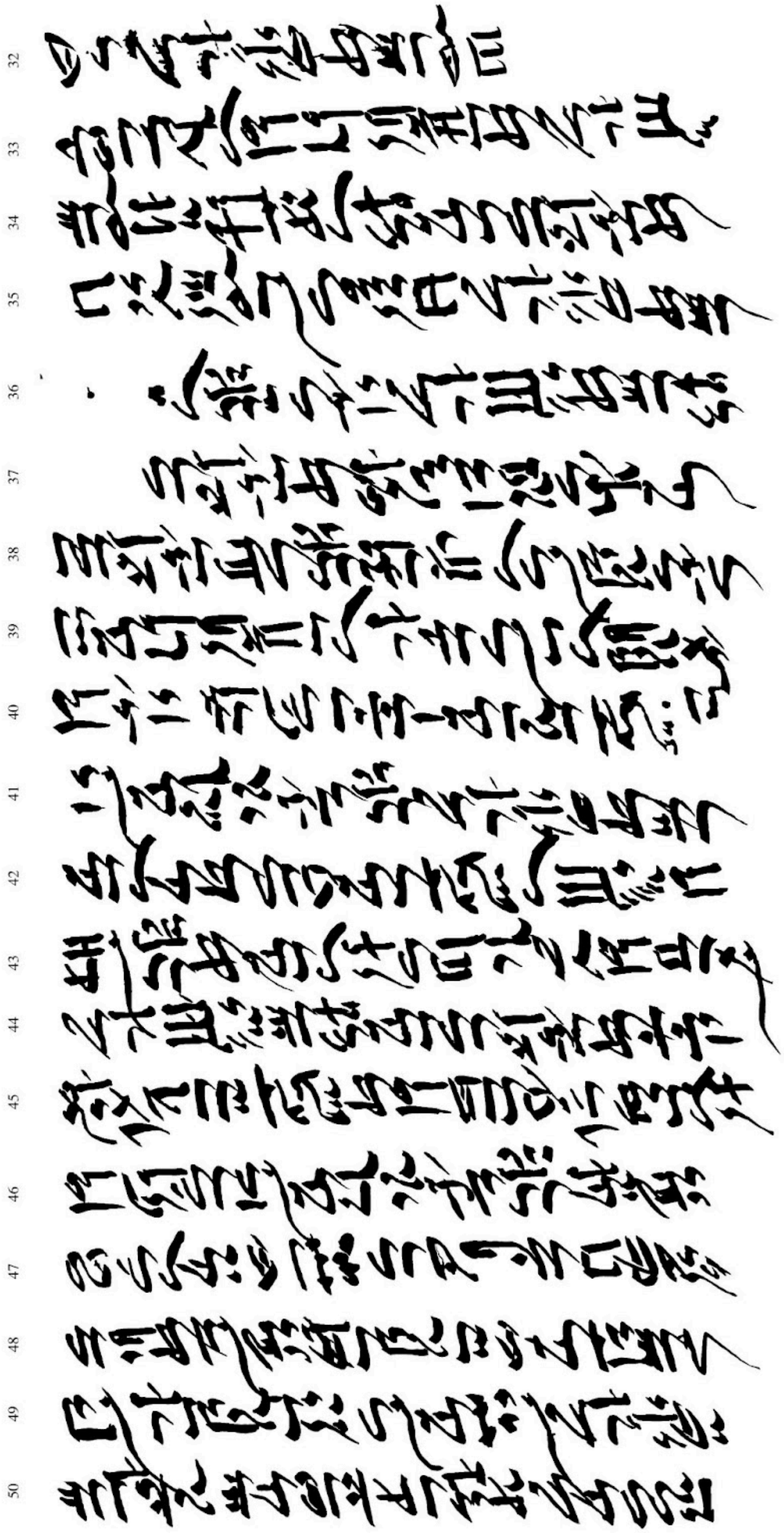
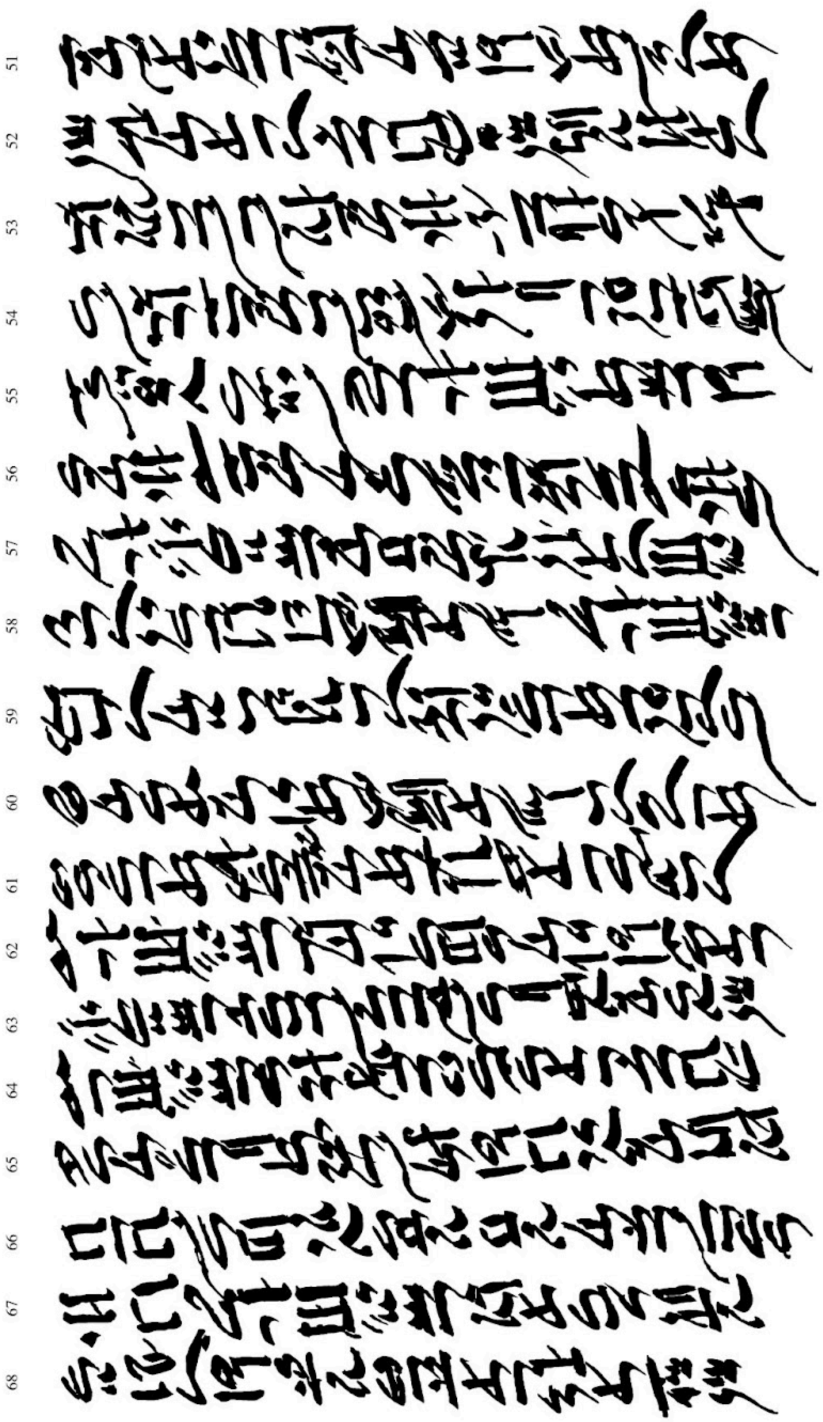
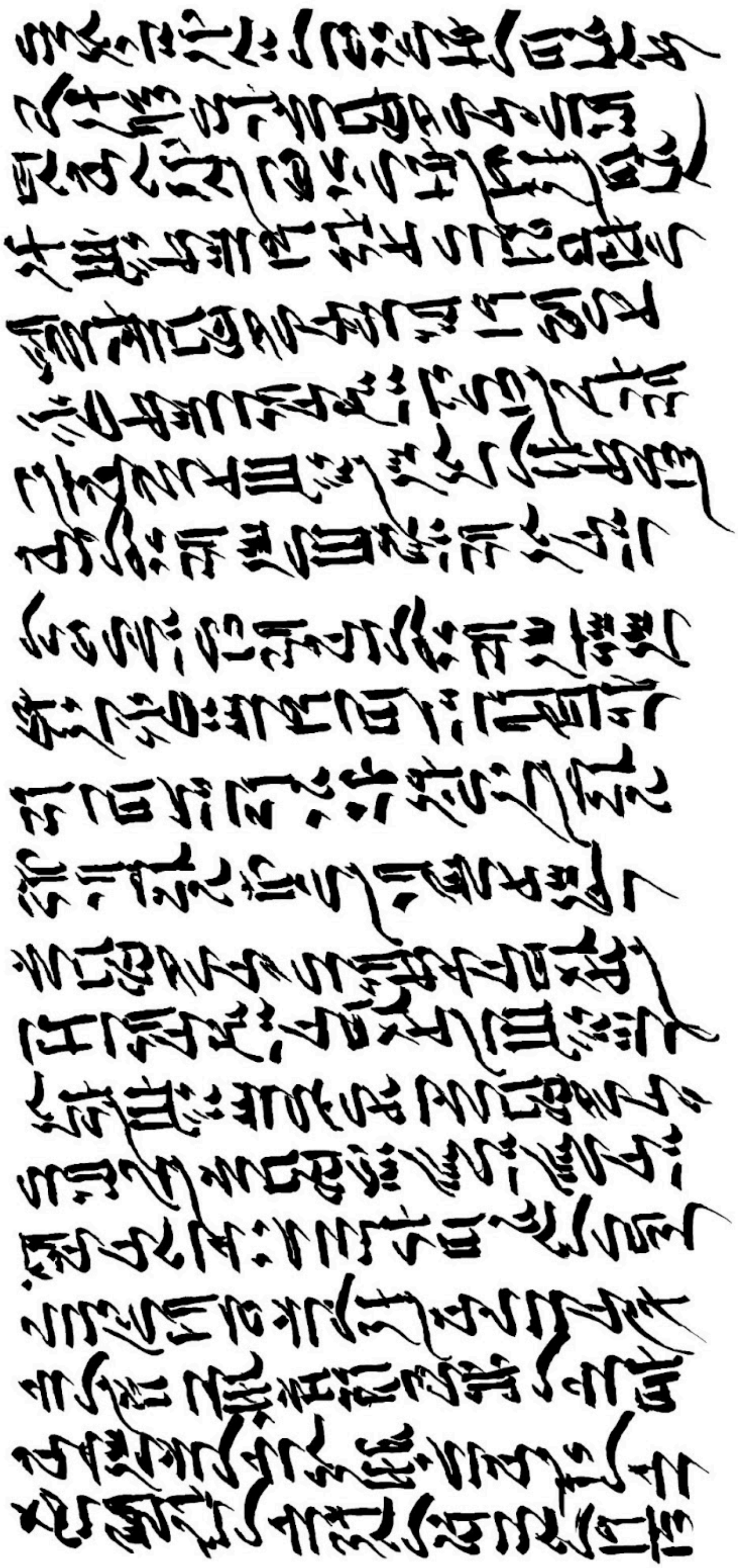
167
168
169

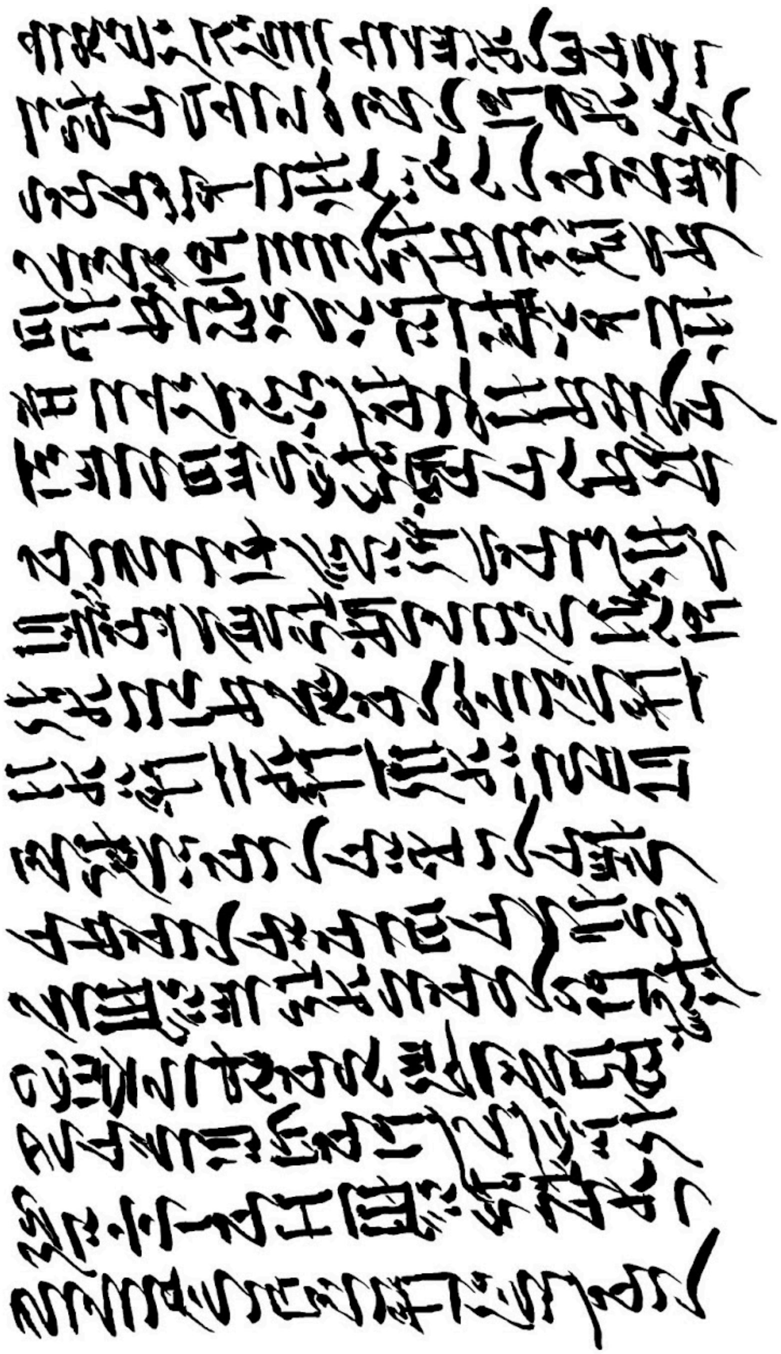


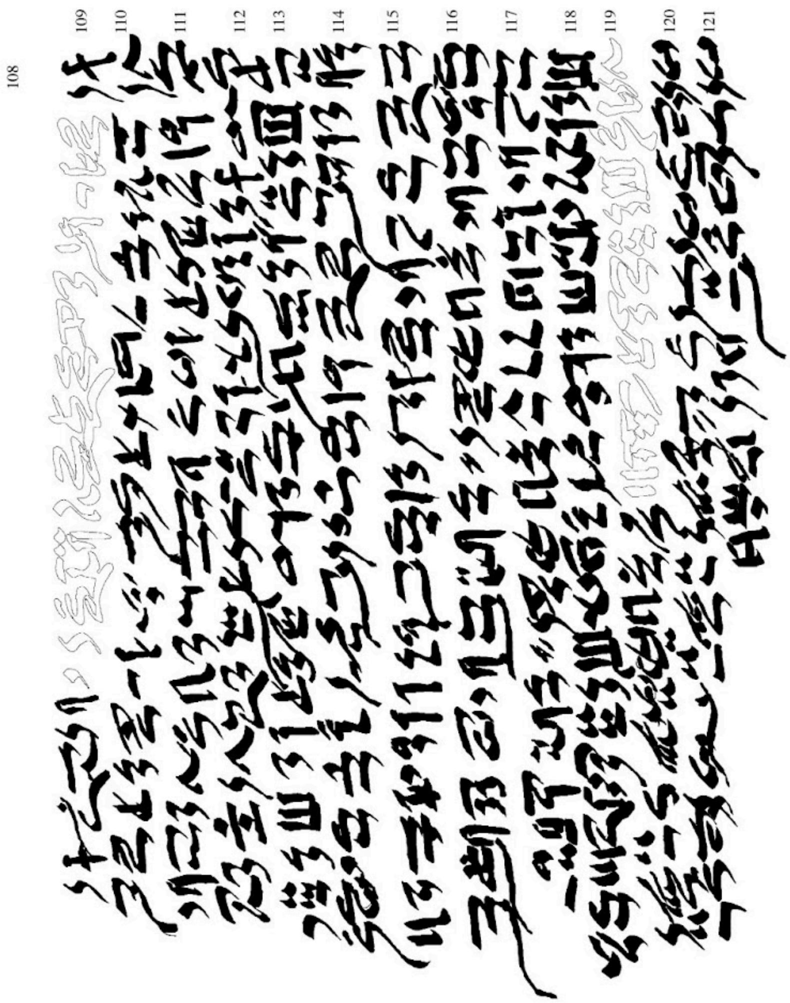












Appendix 3: Code Repository

The code and individual cut out sign images used for this work have been collected in a GitHub repository that is free and accessible. Anyone can follow the URL provided below and download the code and data set. This repository will be continually updated as the data set expands and the program is refined. A “README” file is present in the repository, presenting a more in-depth explanation of the contents. Far more code was created and used to prepare the results shown in this work, but all of the figures and analyses can be reproduced using the slimmed down code and full data set provided at the GitHub repository. The repository can be found at:

https://github.com/jtabin/PaPYrus

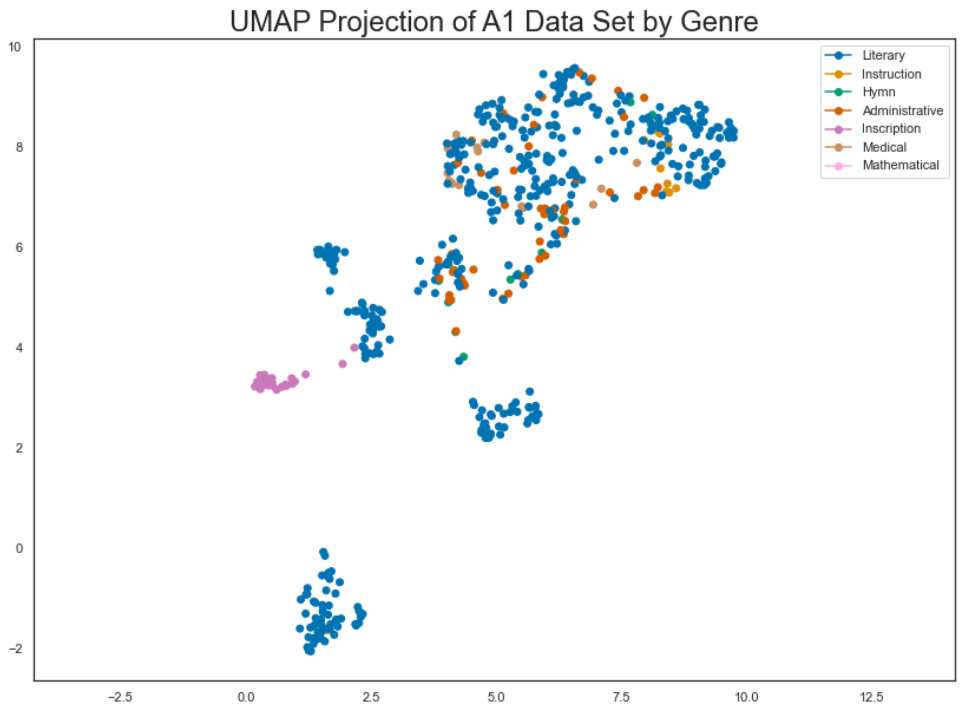
In many ways, this is the most important part of this work. The numerous aforementioned benefits of this program will only materialize through persistent innovation and expansion. This is intended to be a collaborative effort between as many interested scholars as possible for the benefit of all. There are a myriad of directions that the program could be taken in, many more than have been mentioned here and I look forward to seeing how it develops over time.

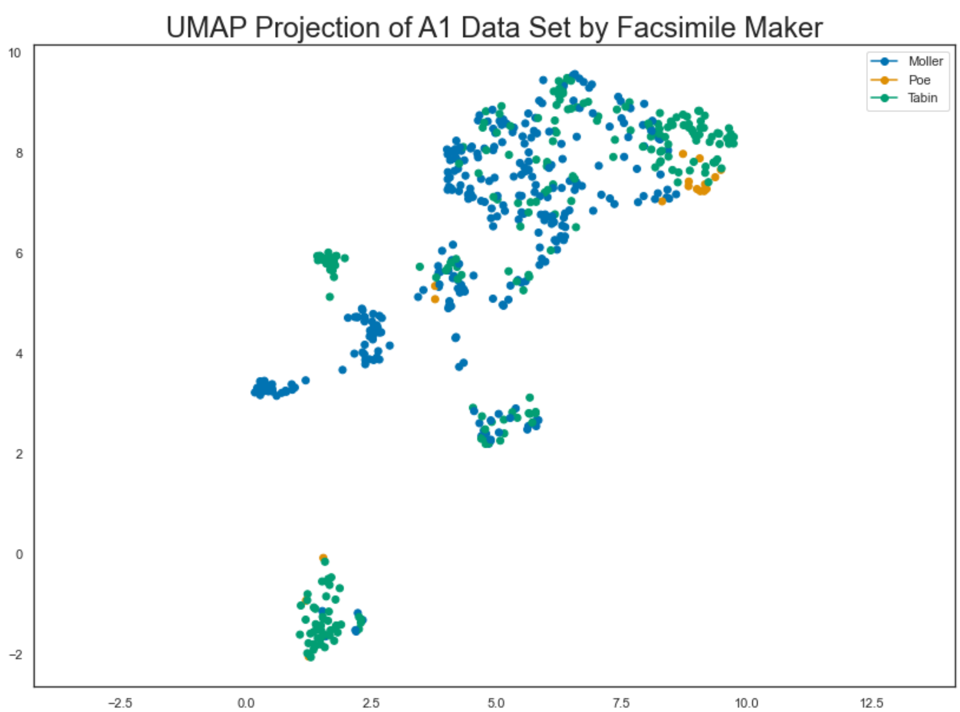
Appendix 4: Further Graphical Examples

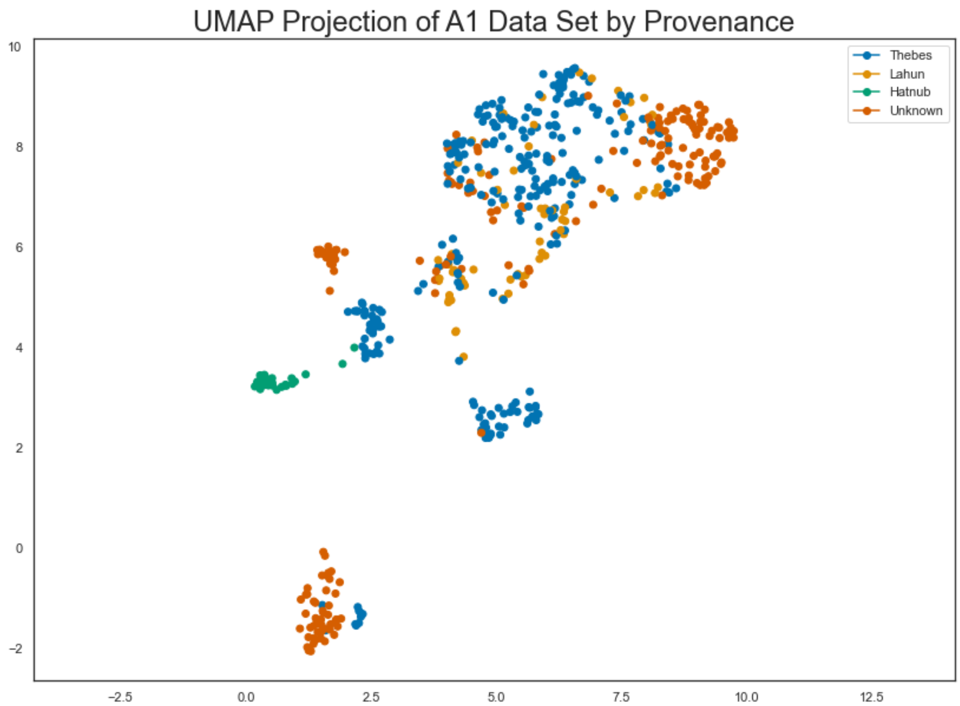
This last appendix contains all of the UMAP graphs for all of the signs that were able to be analyzed by the program in the timespan of this work. Each sign has four corresponding graphs, colored by genre, by facsimile maker, by provenance, and by text. Some graphs are repeats of ones from the Figures section of this paper, but they are reproduced here so they can be compared to the rest. More figures for other signs could be made using the code provided in Appendix 3. The table below contains the signs analyzed and the page numbers for their graphs.

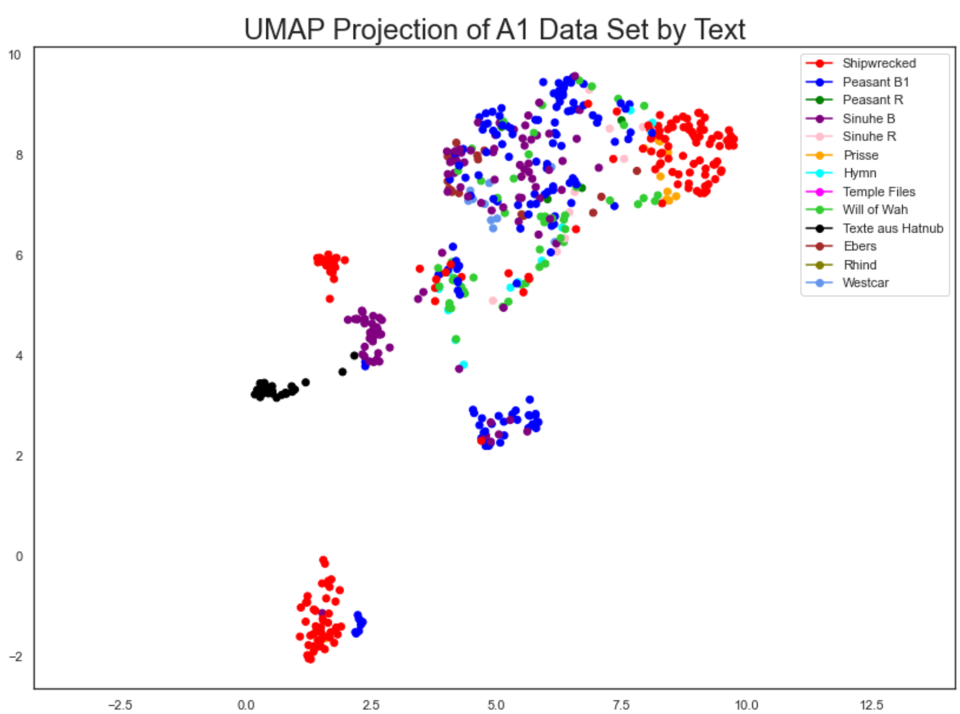
Sign	Pages
A1	182-183
A2	184-185
A19	186-187
A24	188-189
Aa1	190-191
D2	192-193
D21	194-195
D35	196-197
D46	198-199
F31	200-201
G1	202-203
G17_X1	204-205
G28	206-207
G43	208-209
I9	210-211
I10	212-213
M17	214-215
M18	216-217

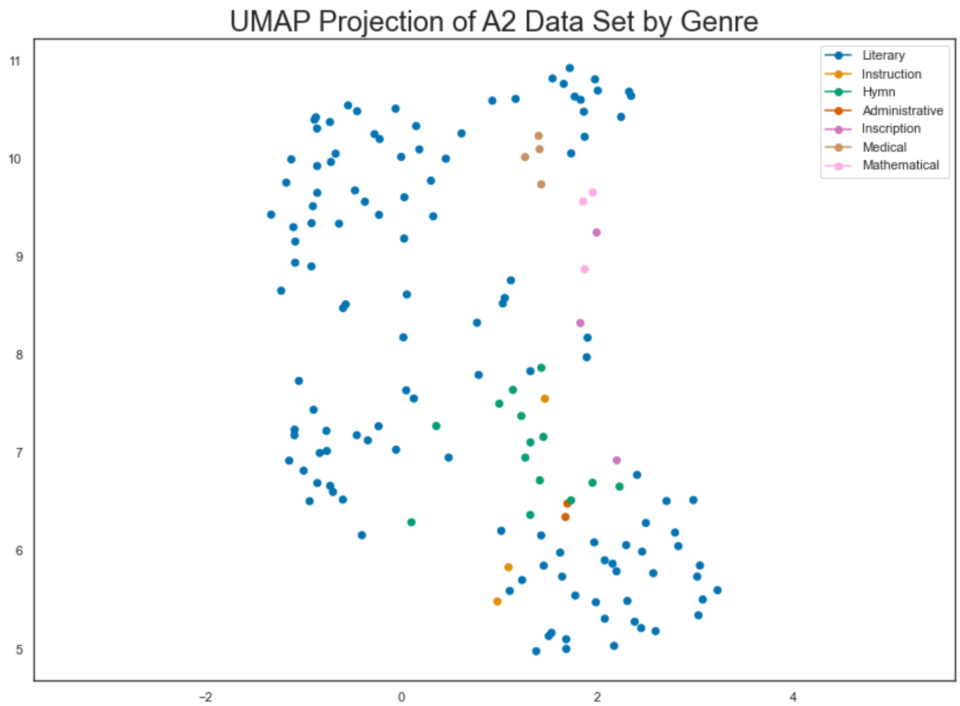
Sign	Pages
N5	218-219
N14	220-221
N35_I9	222-223
N35	224-225
O29	226-227
O34	228-229
O49	230-231
Q7	232-233
S29	234-235
V28	236-237
V30	238-239
W11	240-241
W17	242-243
X1	244-245
Y1	246-247
Z1	248-249
Z2	250-251

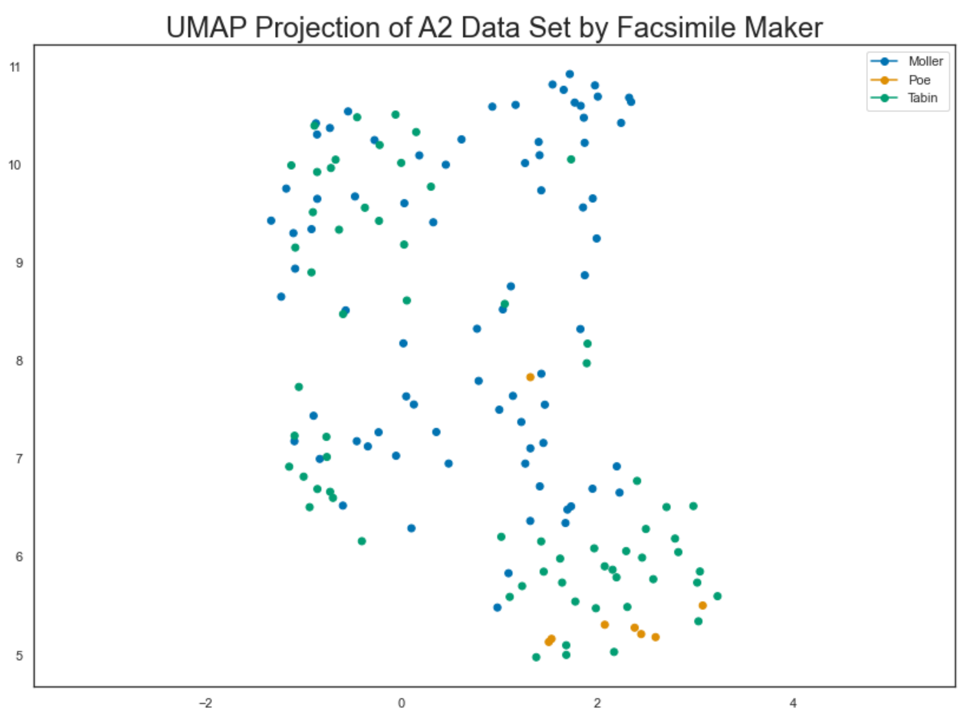

UMAP Projection of A1 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
10
8
6
4
2
0
−2
−2.5
0.0
2.5
5.0
7.5
10.0
12.5

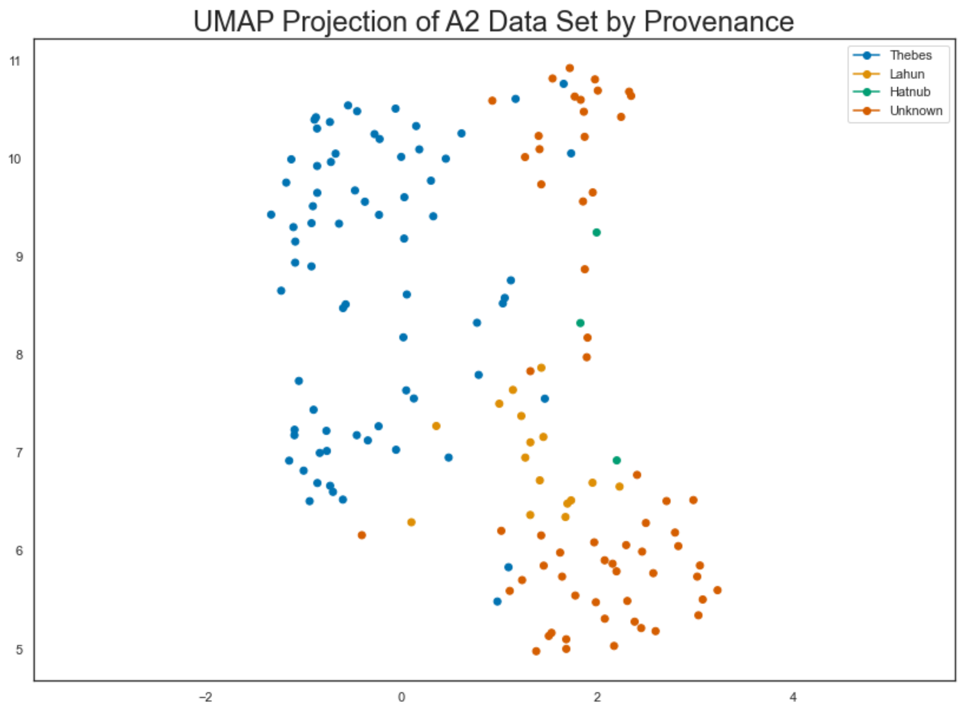

UMAP Projection of A1 Data Set by Facsimile Maker
Moller
Poe
Tabin
10
8
6
4
2
0
−2
−2.5
0.0
2.5
5.0
7.5
10.0
12.5

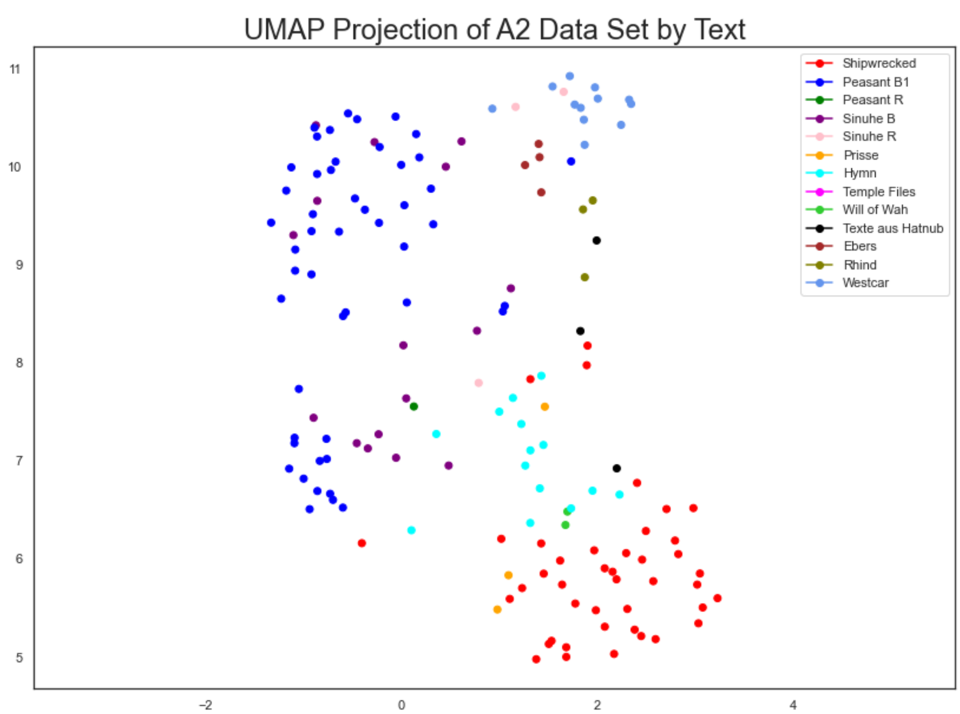

UMAP Projection of A1 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
10
8
6
4
2
0
−2
−2.5
0.0
2.5
5.0
7.5
10.0
12.5

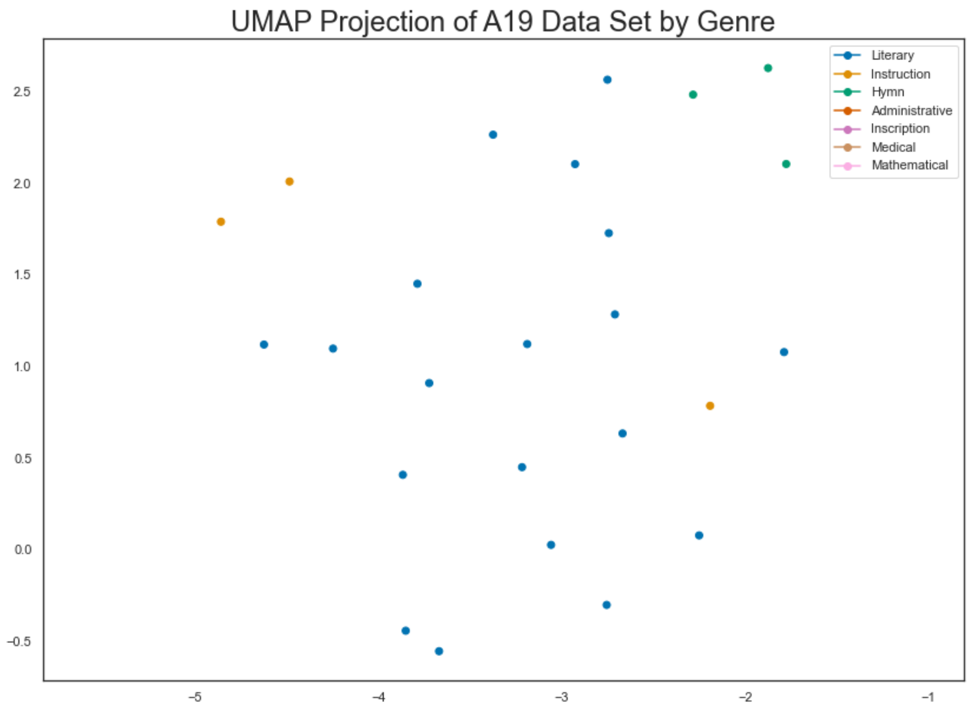

UMAP Projection of A1 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
10
8
6
4
2
0
−2
−2.5
0.0
2.5
5.0
7.5
10.0
12.5

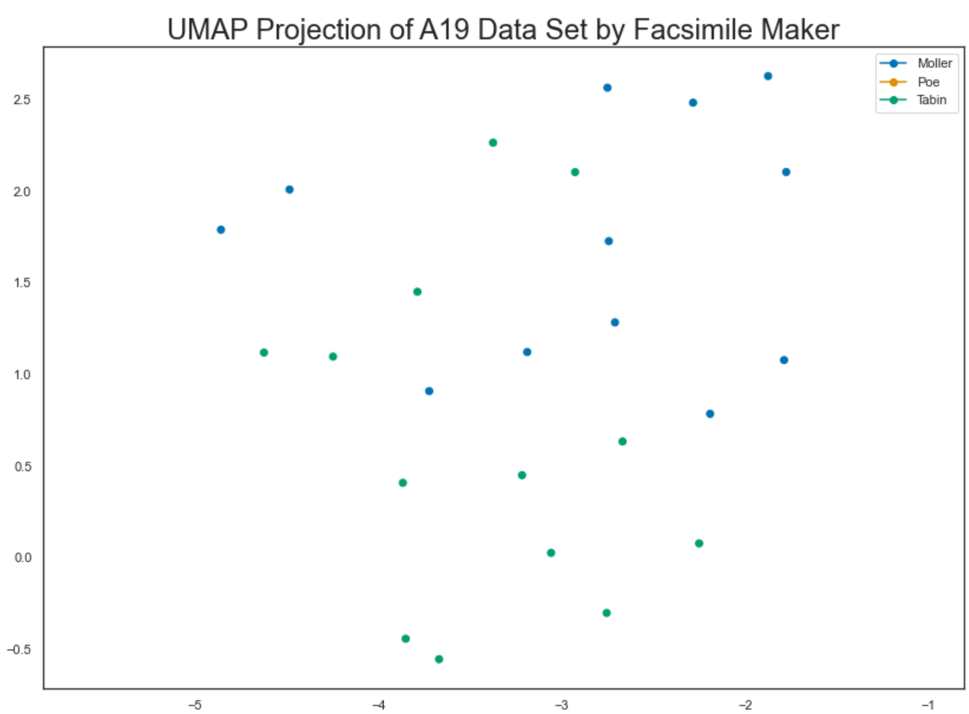

UMAP Projection of A2 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
11
10
9
8
7
6
5
−2
0
2
4

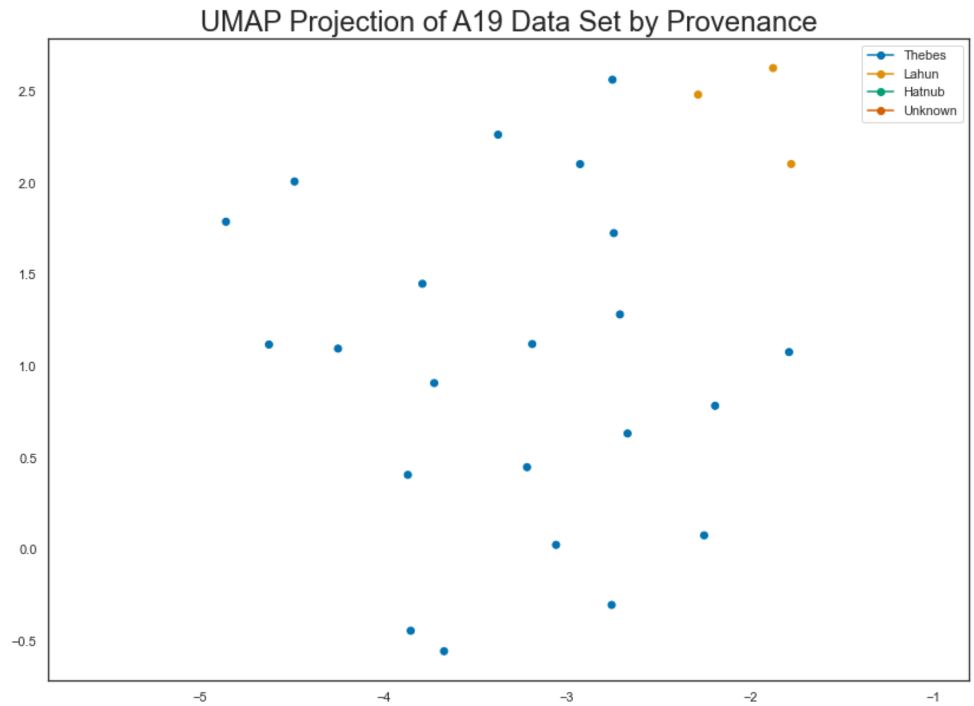

UMAP Projection of A2 Data Set by Facsimile Maker
Moller
Poe
Tabin
11
10
9
8
7
6
5
−2
0
2
4

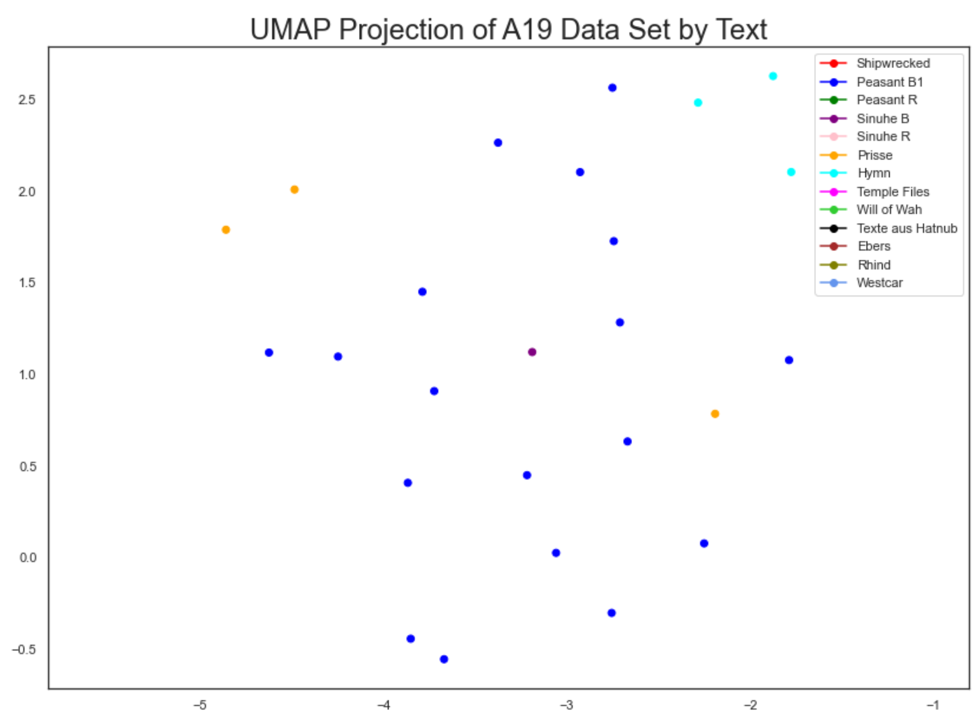

UMAP Projection of A2 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
11
10
9
8
7
6
5
−2
0
2
4

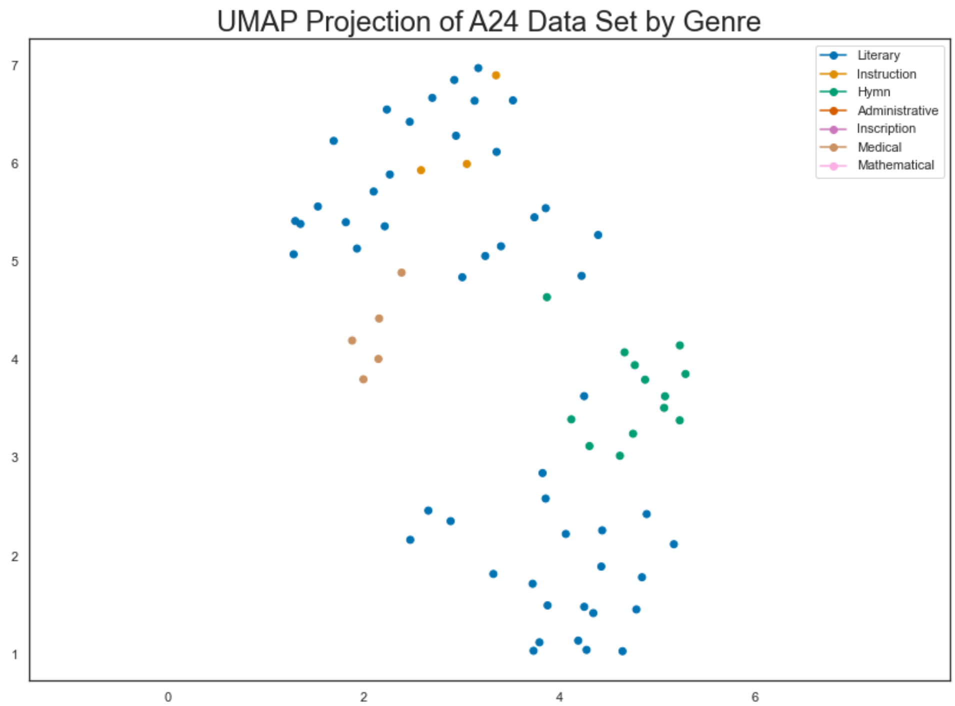

UMAP Projection of A2 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
11
10
9
8
7
6
5
−2
0
2
4

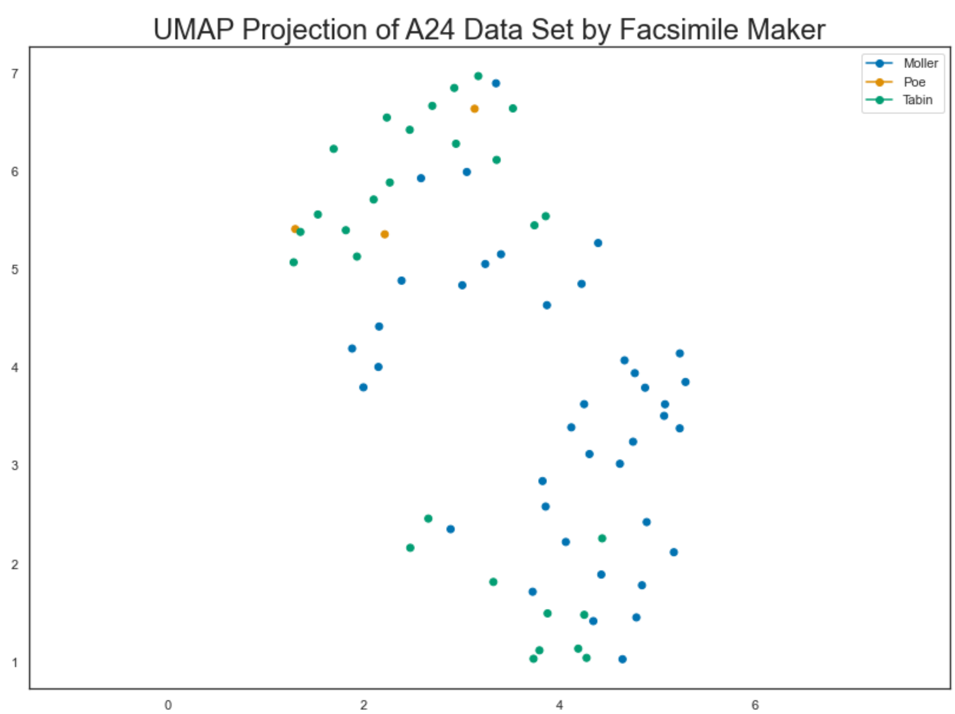

UMAP Projection of A19 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−5
−4
−3
−2
−1

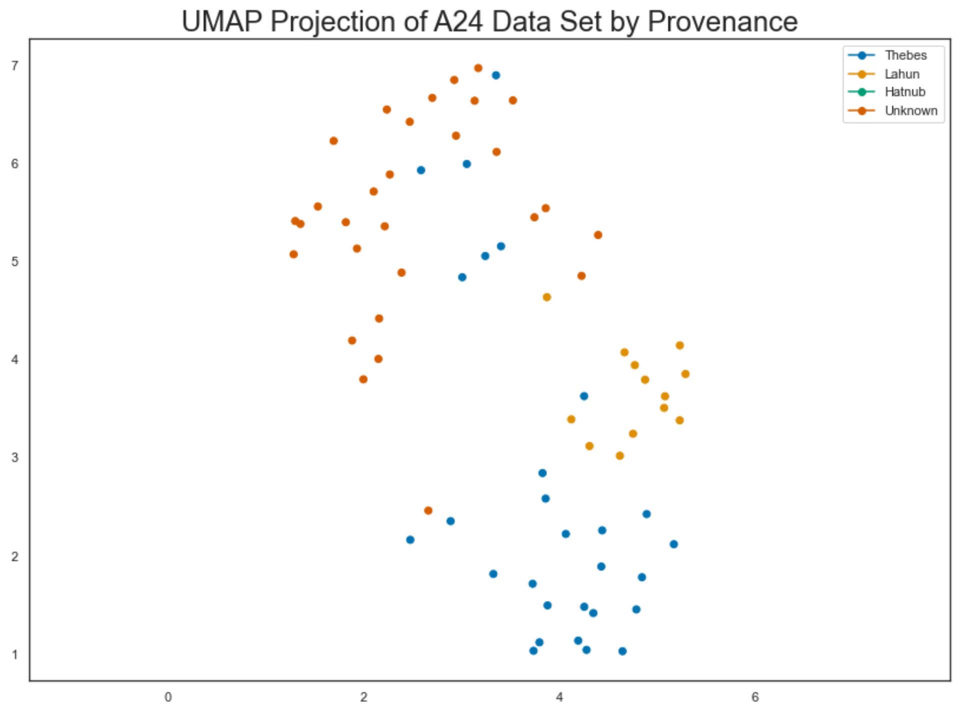

UMAP Projection of A19 Data Set by Facsimile Maker
Moller
Poe
Tabin
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−5
−4
−3
−2
−1

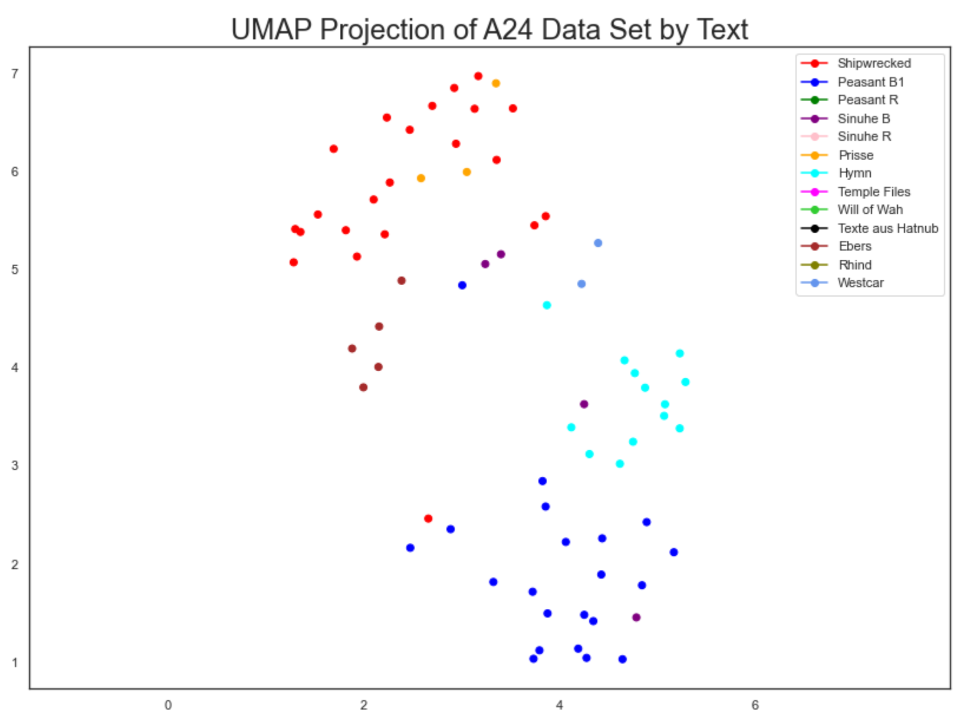

UMAP Projection of A19 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−5
−4
−3
−2
−1

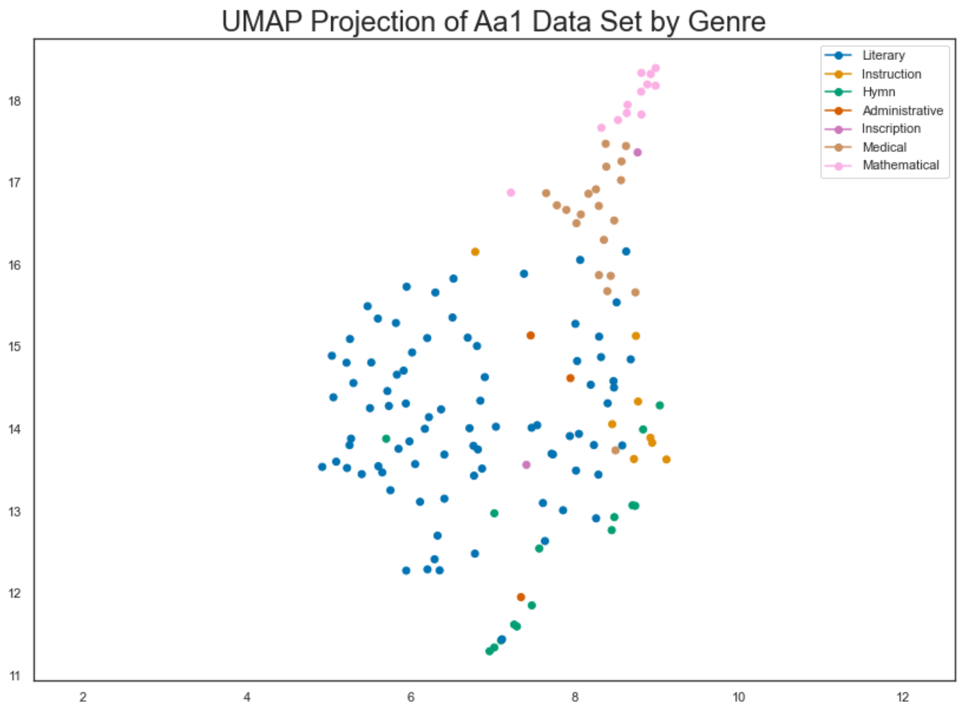

UMAP Projection of A19 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−5
−4
−3
−2
−1

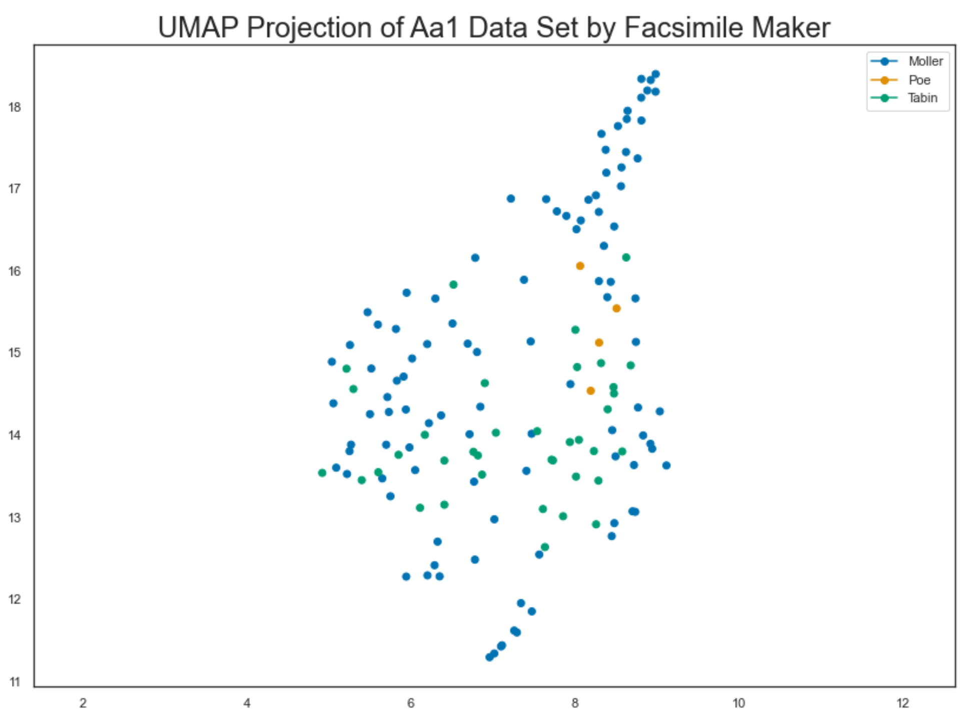

UMAP Projection of A24 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
7
6
5
4
3
2
1
0
2
4
6

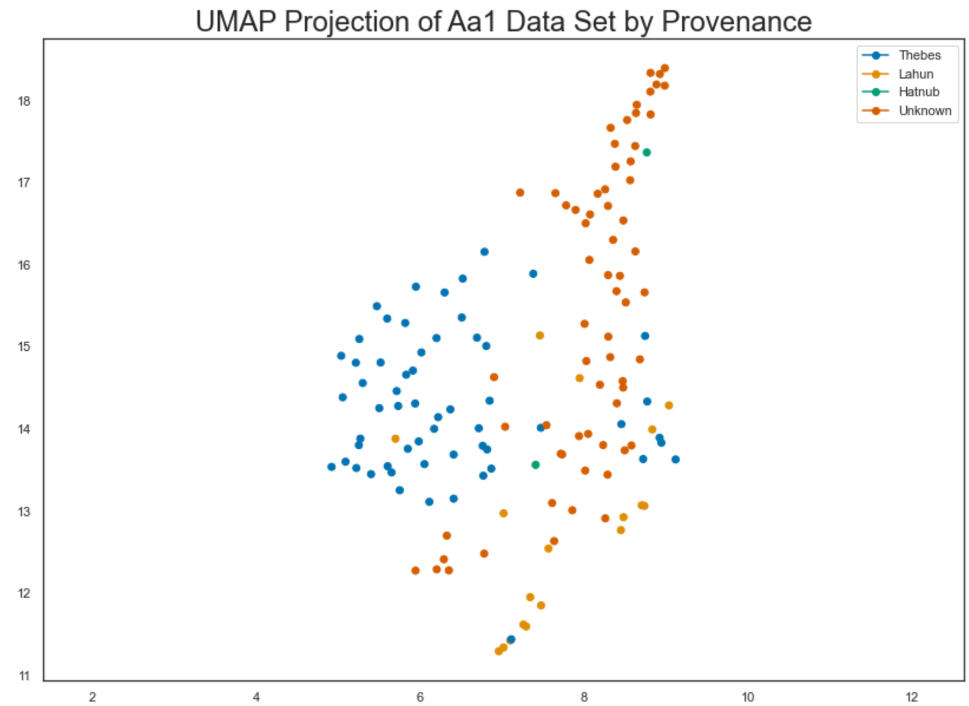

UMAP Projection of A24 Data Set by Facsimile Maker
Moller
Poe
Tabin
7
6
5
4
3
2
1
0
2
4
6

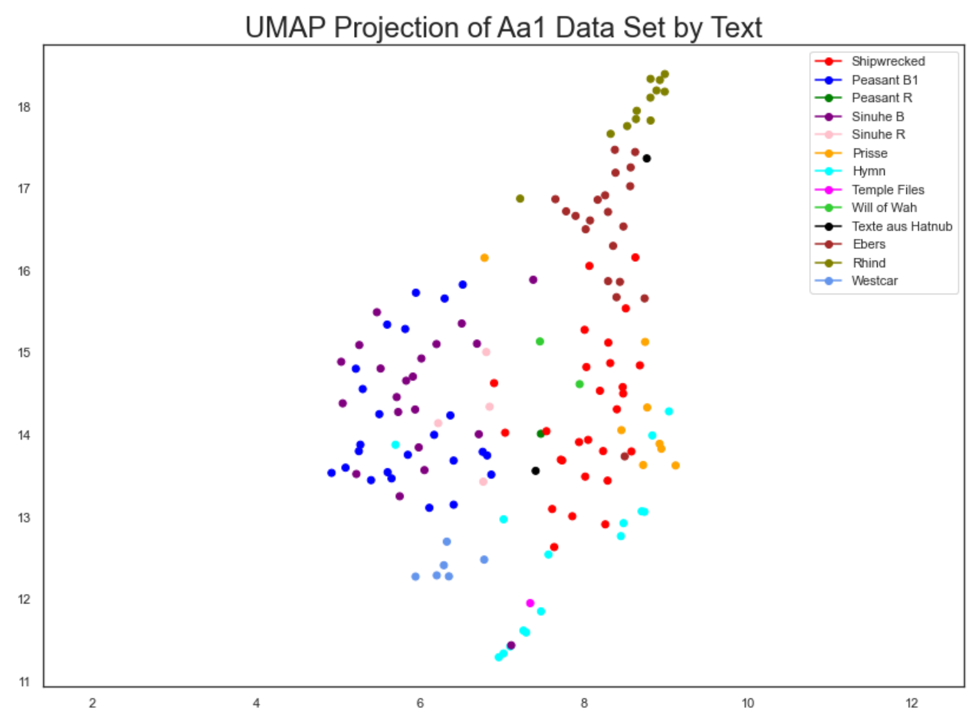

UMAP Projection of A24 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
7
6
5
4
3
2
1
0
2
4
6

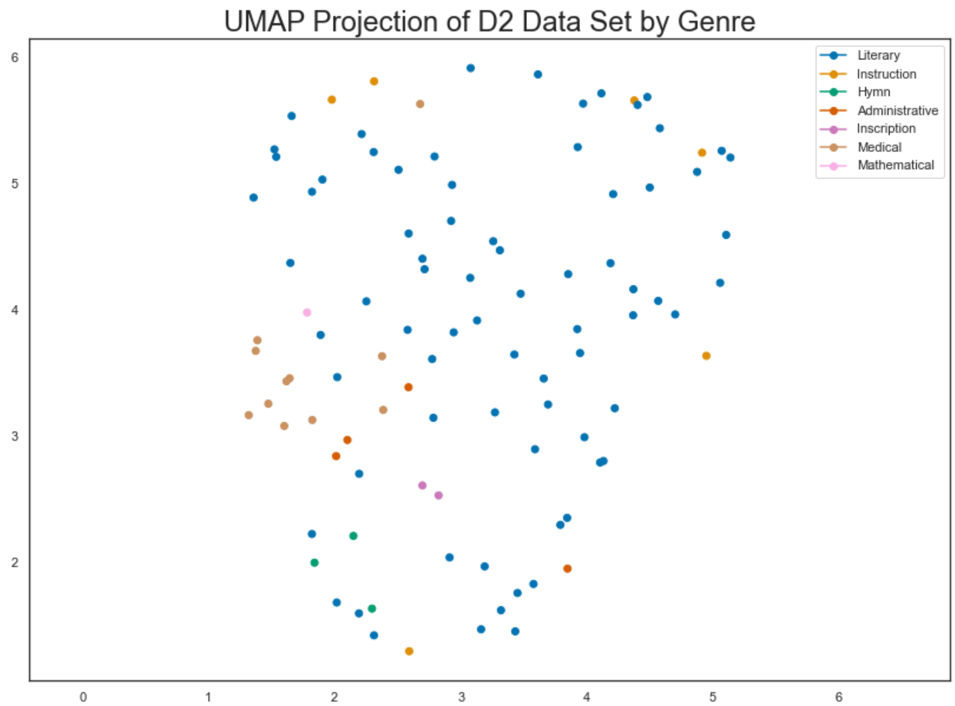

UMAP Projection of A24 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
7
6
5
4
3
2
1
0
2
4
6

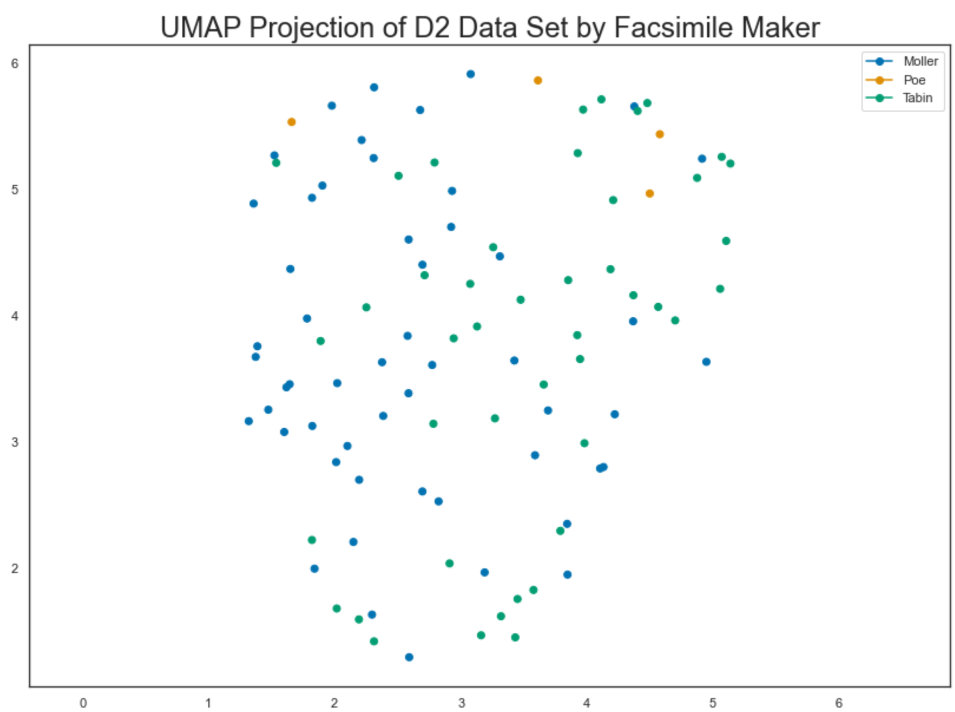

UMAP Projection of Aa1 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
18
17
16
15
14
13
12
11
2
4
6
8
10
12

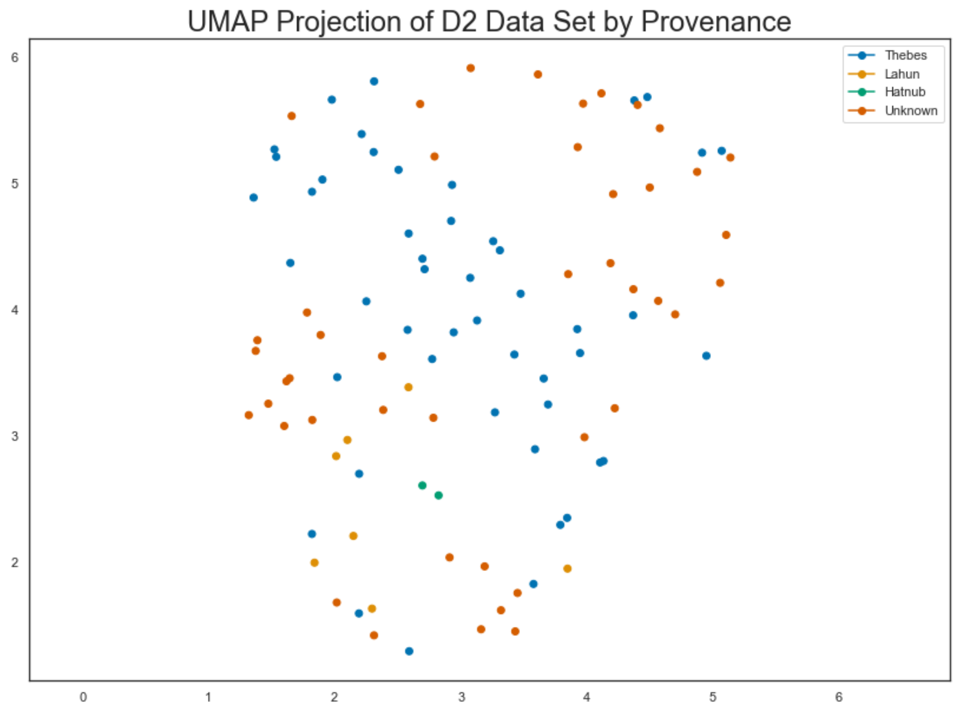

UMAP Projection of Aa1 Data Set by Facsimile Maker
Moller
Poe
Tabin
18
17
16
15
14
13
12
11
2
4
6
8
10
12

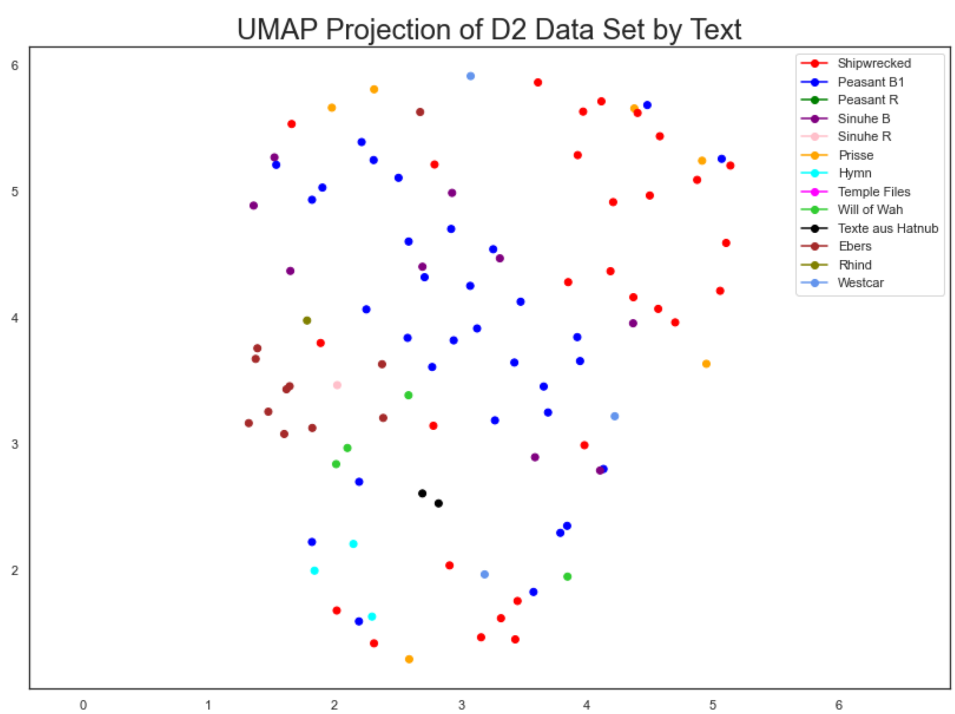

UMAP Projection of Aa1 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
11
12
13
14
15
16
17
18
2
4
6
8
10
12

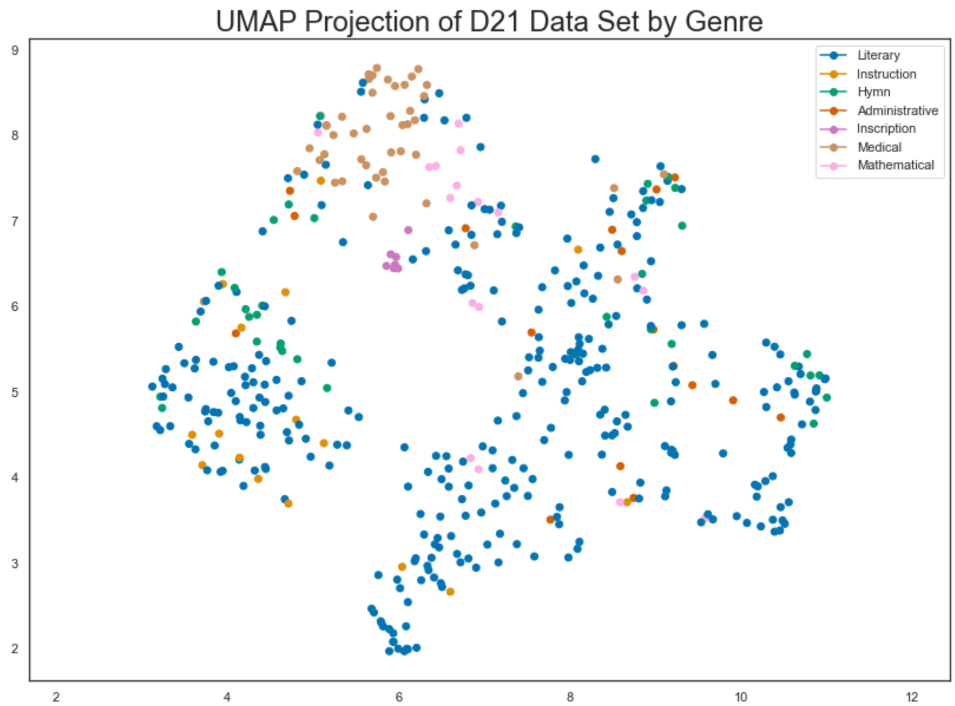

UMAP Projection of Aa1 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
11
12
13
14
15
16
17
18
2
4
6
8
10
12

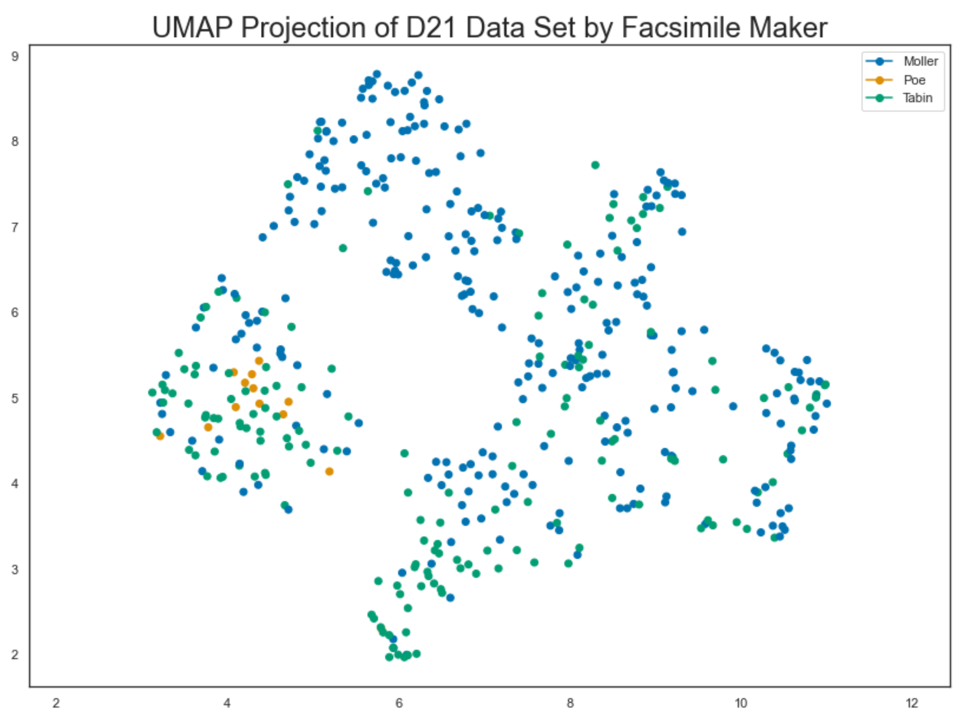

UMAP Projection of D2 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
0
1
2
3
4
5
6

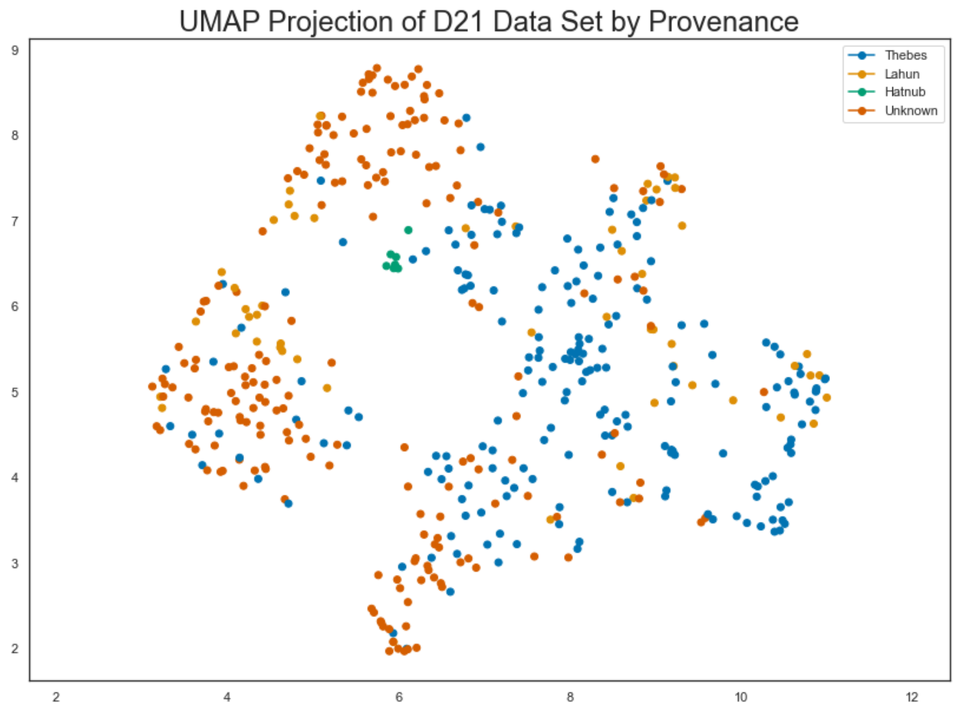

UMAP Projection of D2 Data Set by Facsimile Maker
Moller
Poe
Tabin
0
1
2
3
4
5
6

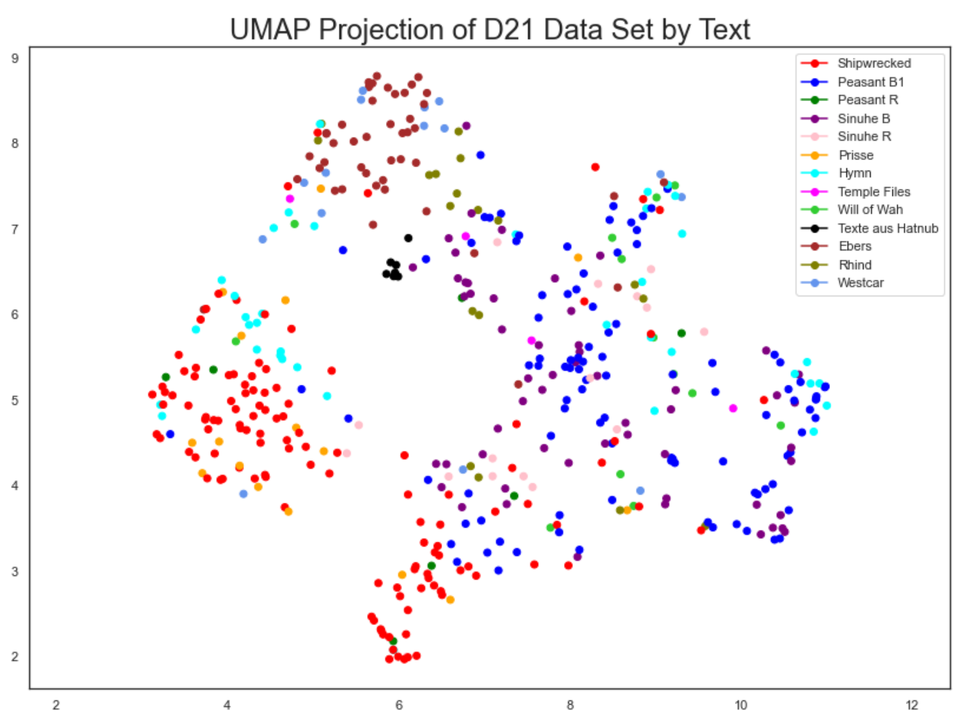

UMAP Projection of D2 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
6
5
4
3
2
0
1
2
3
4
5
6

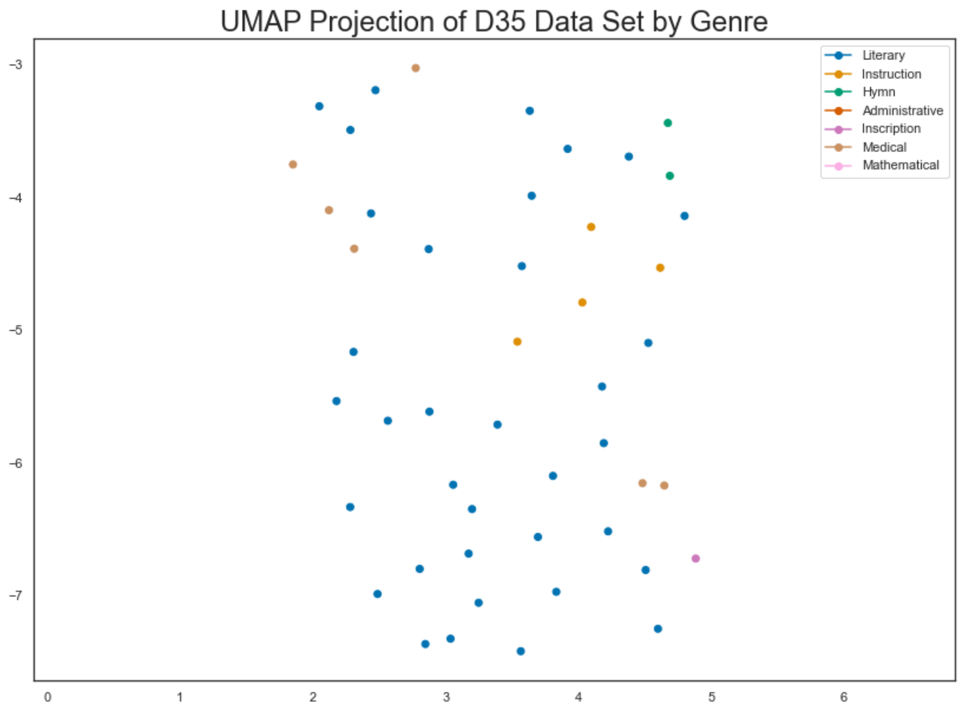

UMAP Projection of D2 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
6
5
4
3
2
0
1
2
3
4
5
6

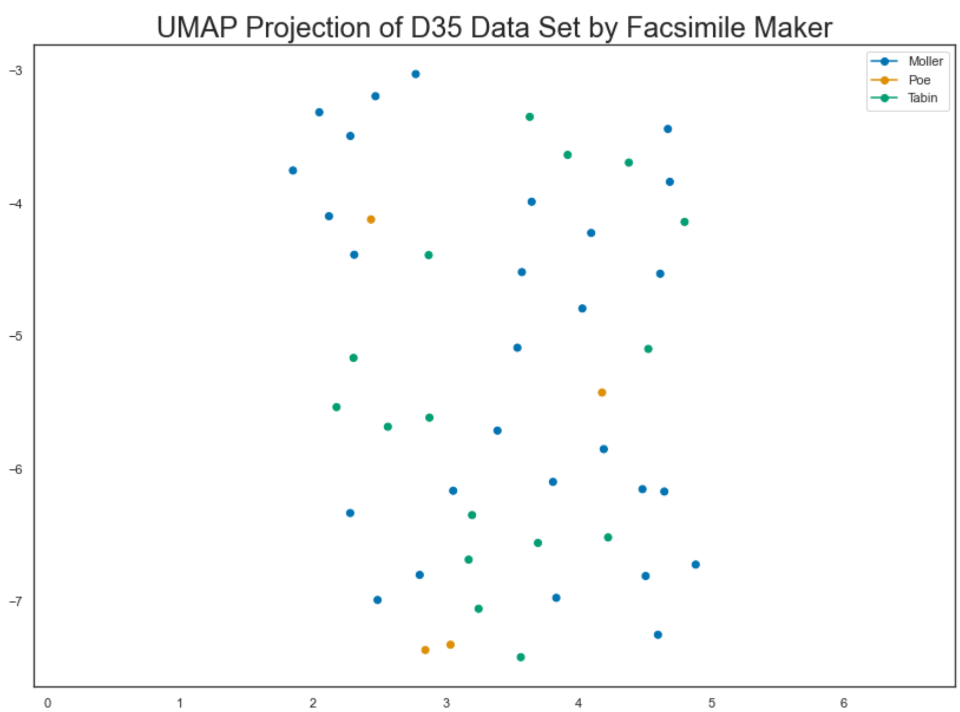

UMAP Projection of D21 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
9
8
7
6
5
4
3
2
2
4
6
8
10
12

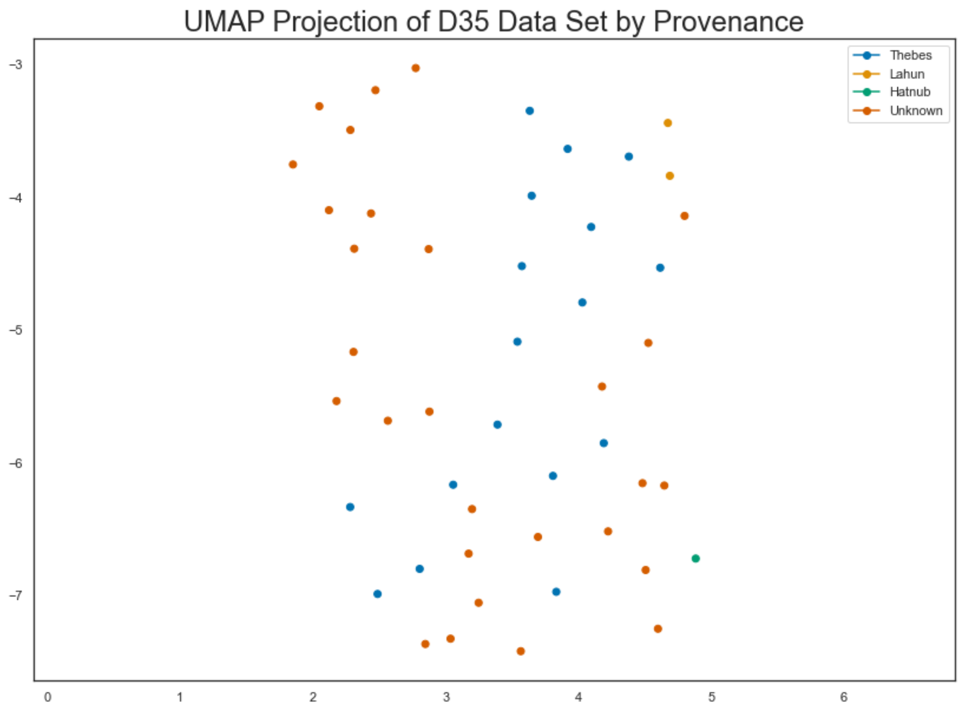

UMAP Projection of D21 Data Set by Facsimile Maker
Moller
Poe
Tabin
9
8
7
6
5
4
3
2
2
4
6
8
10
12


UMAP Projection of D21 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
9
8
7
6
5
4
3
2
2
4
6
8
10
12

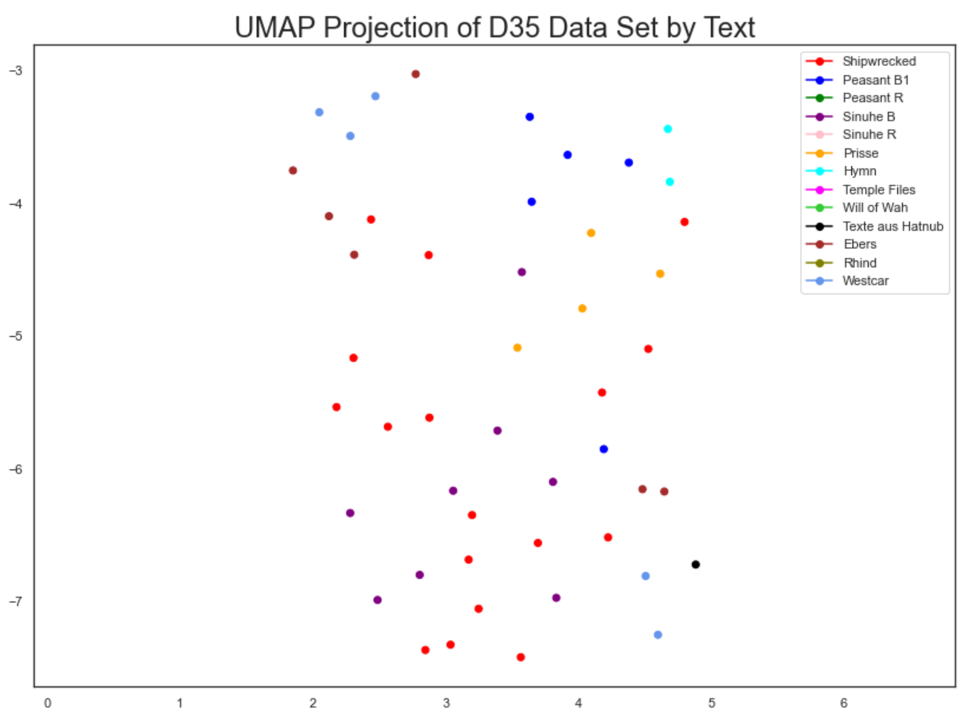

UMAP Projection of D21 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
9
8
7
6
5
4
3
2
2
4
6
8
10
12


UMAP Projection of D35 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
-3
-4
-5
-6
-7
0
1
2
3
4
5
6

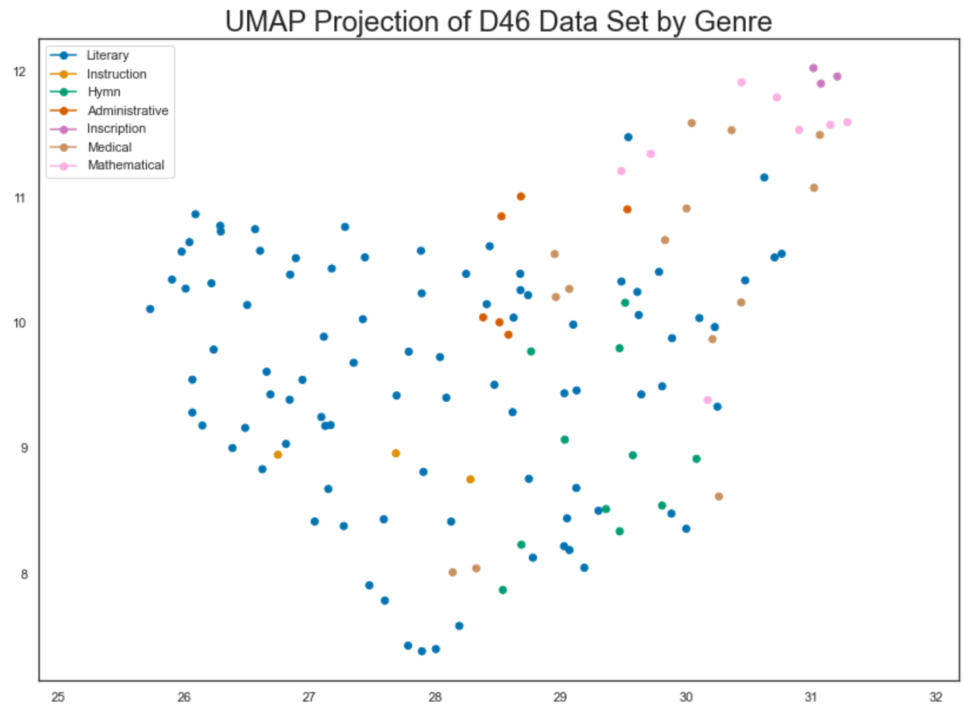

UMAP Projection of D35 Data Set by Facsimile Maker
Moller
Poe
Tabin
-3
-4
-5
-6
-7
0
1
2
3
4
5
6

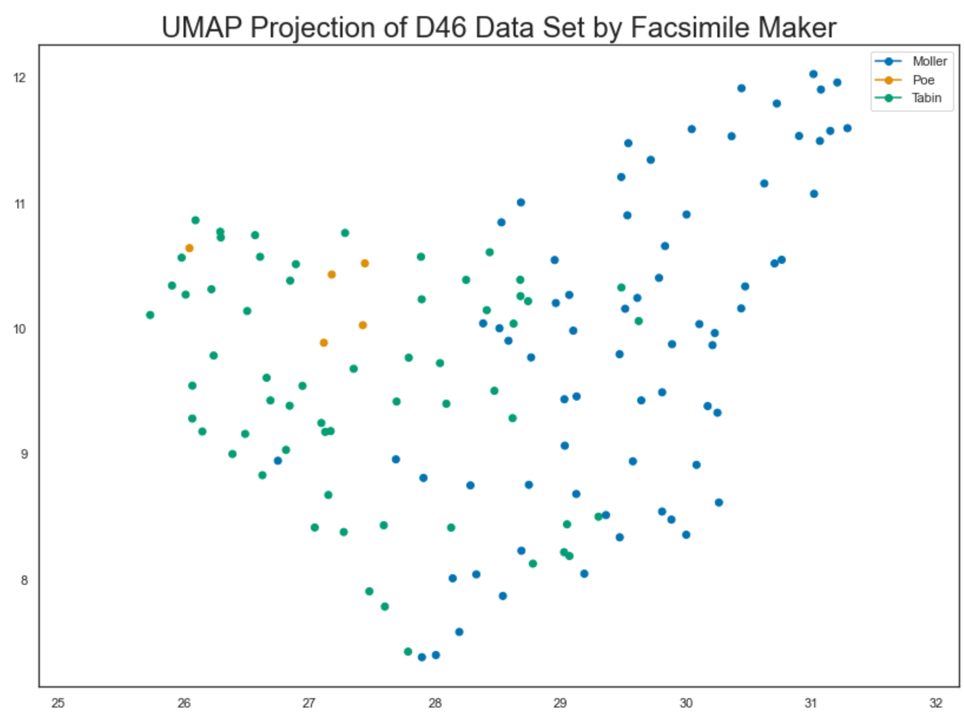


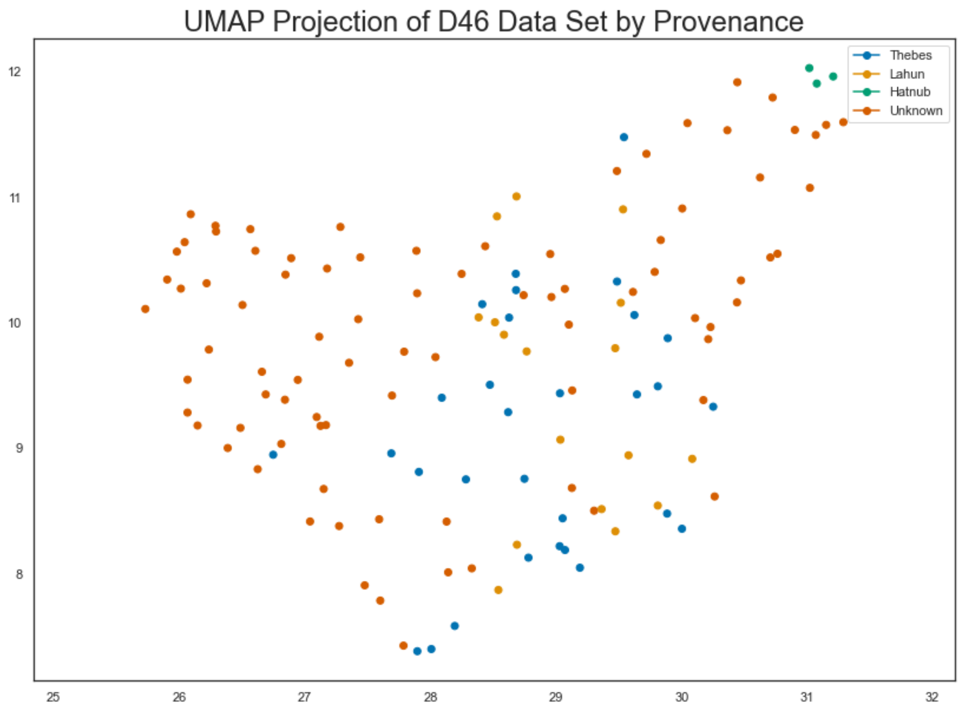
UMAP Projection of D35 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
-3
-4
-5
-6
-7
0
1
2
3
4
5
6

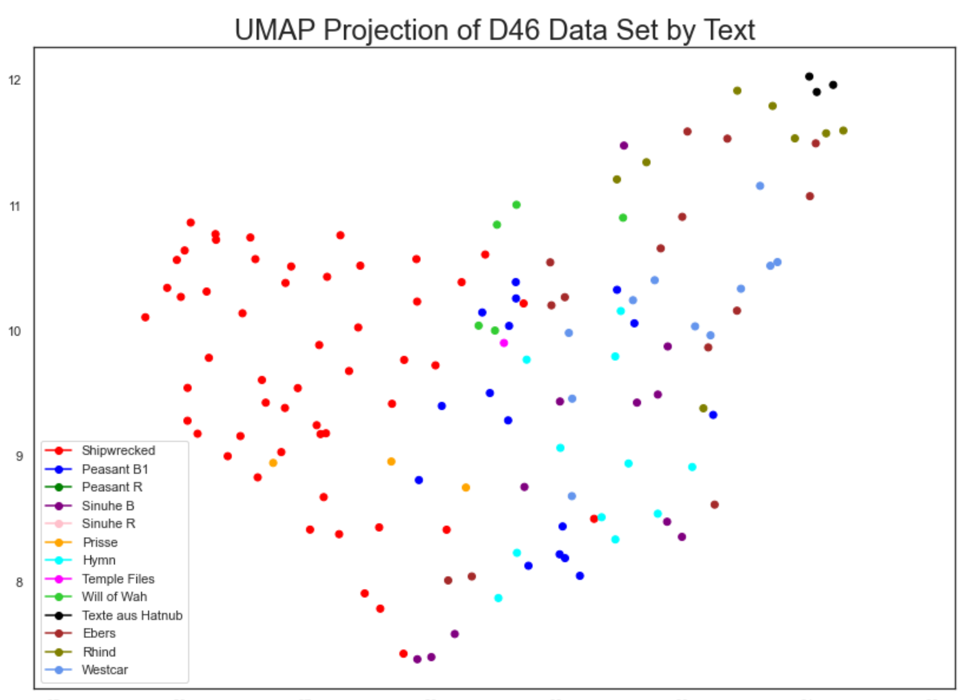


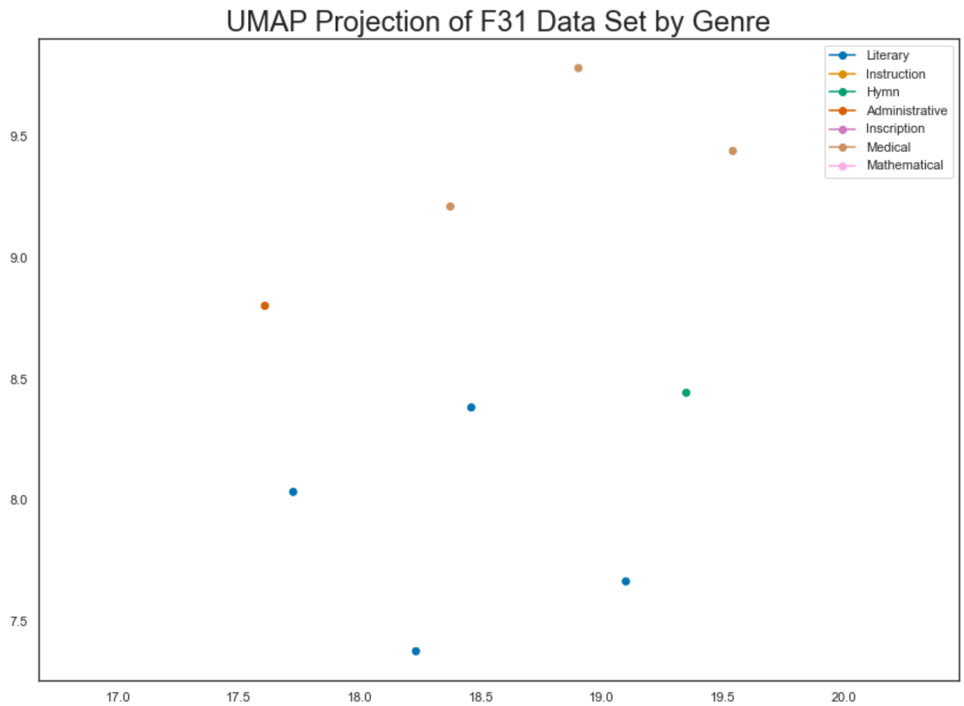
UMAP Projection of D35 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
-3
-4
-5
-6
-7
0
1
2
3
4
5
6

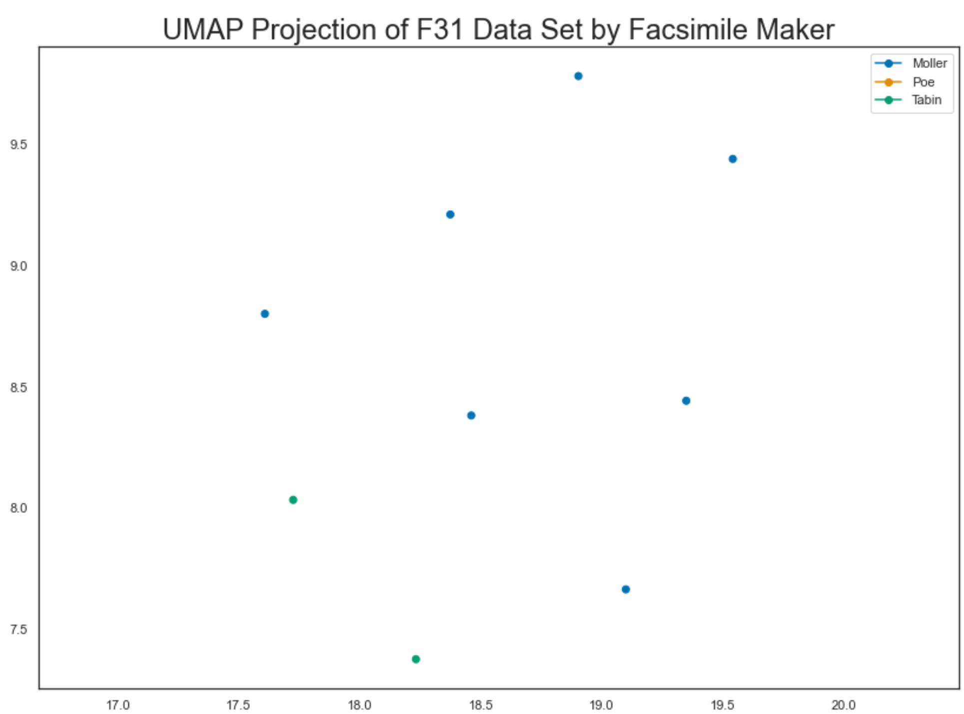

UMAP Projection of D46 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
12
11
10
9
8
25
26
27
28
29
30
31
32

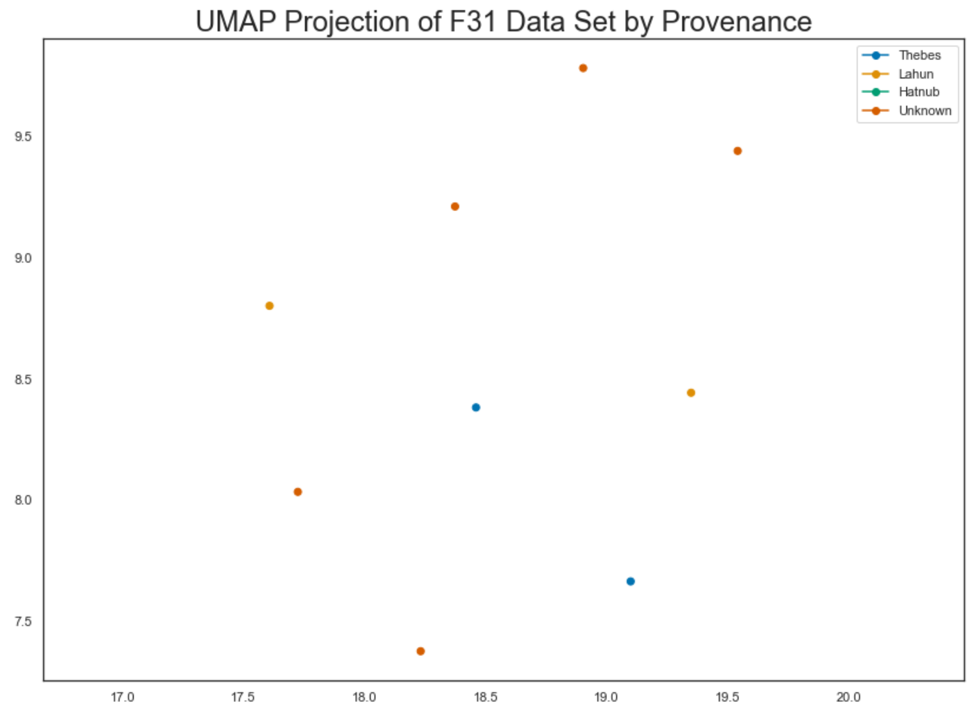

UMAP Projection of D46 Data Set by Facsimile Maker
Moller
Poe
Tabin
12
11
10
9
8
25
26
27
28
29
30
31
32

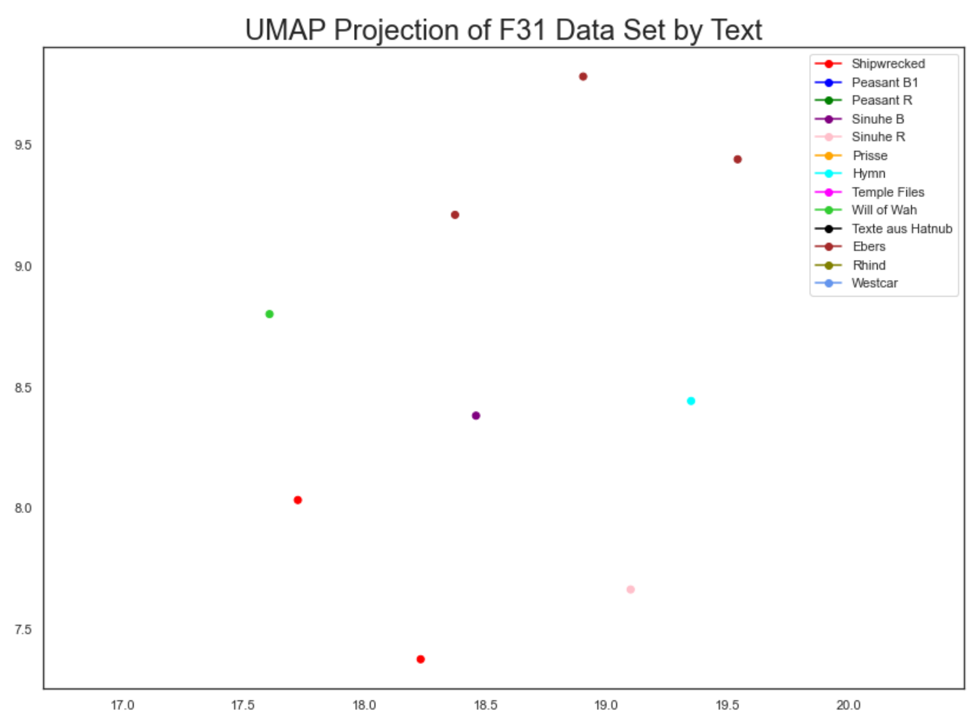

UMAP Projection of D46 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
12
11
10
9
8
25
26
27
28
29
30
31
32

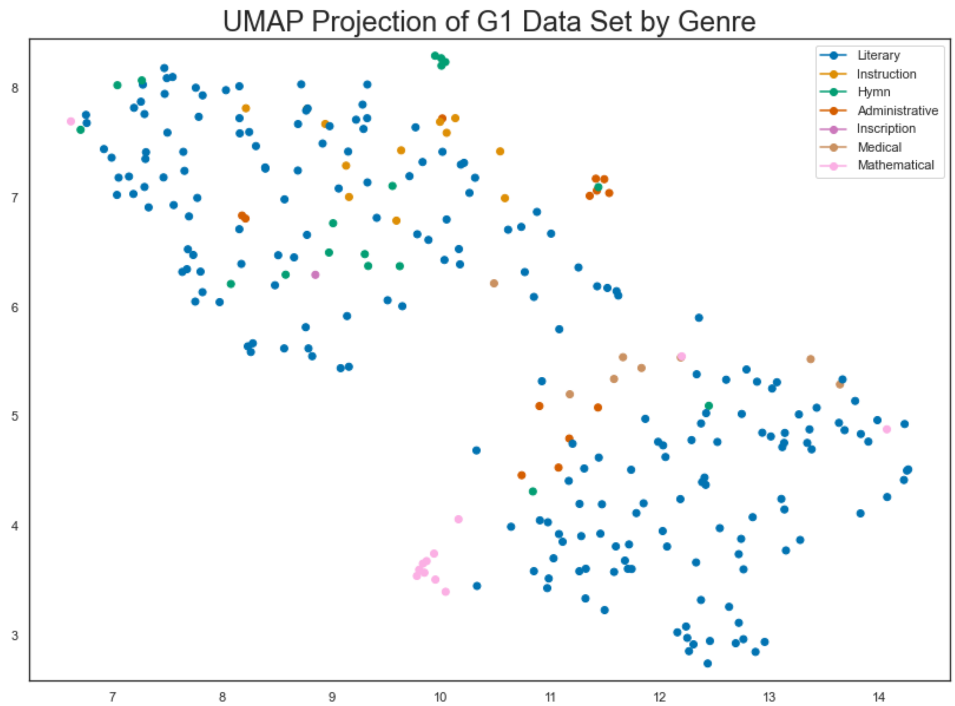

UMAP Projection of D46 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
12
11
10
9
8
25
26
27
28
29
30
31
32

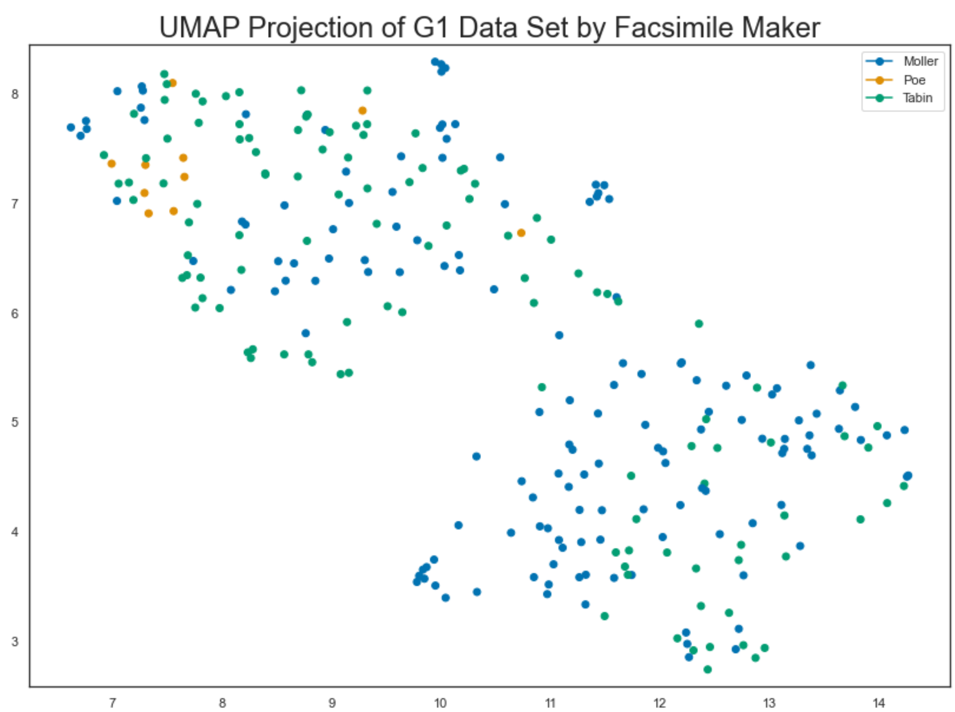

UMAP Projection of F31 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
9.5
9.0
8.5
8.0
7.5
17.0
17.5
18.0
18.5
19.0
19.5
20.0

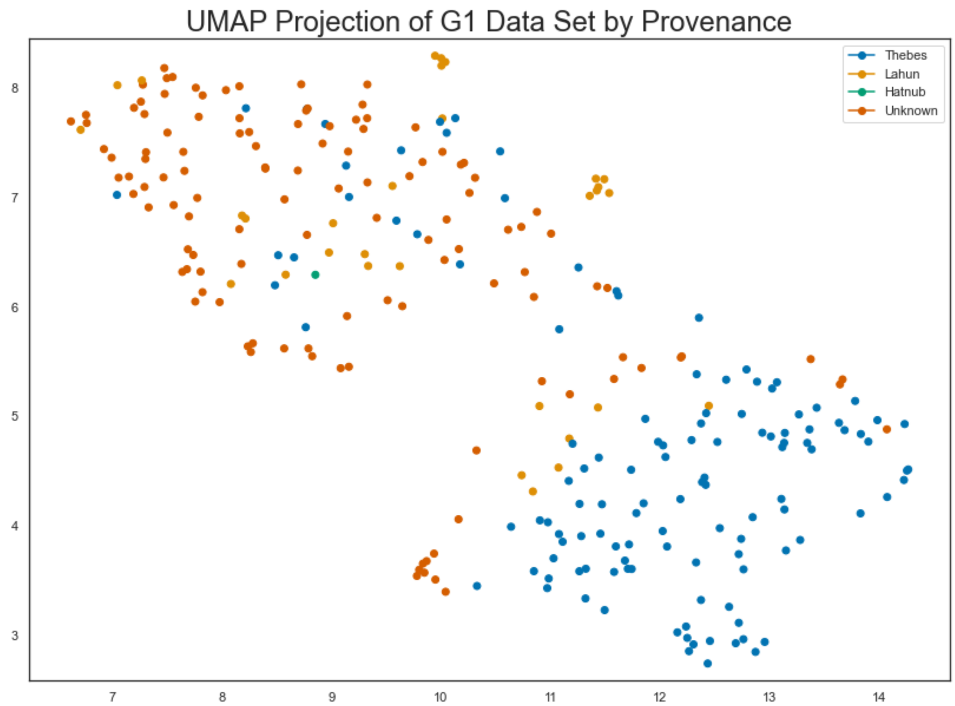

UMAP Projection of F31 Data Set by Facsimile Maker
Moller
Poe
Tabin
9.5
9.0
8.5
8.0
7.5
17.0
17.5
18.0
18.5
19.0
19.5
20.0

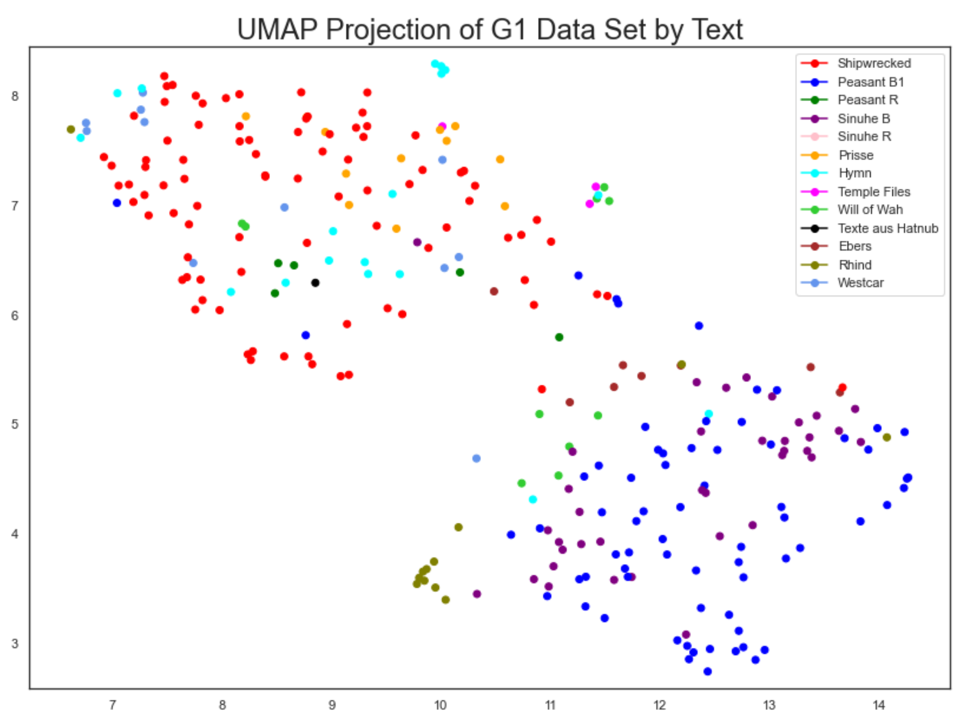

UMAP Projection of F31 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
9.5
9.0
8.5
8.0
7.5
17.0
17.5
18.0
18.5
19.0
19.5
20.0

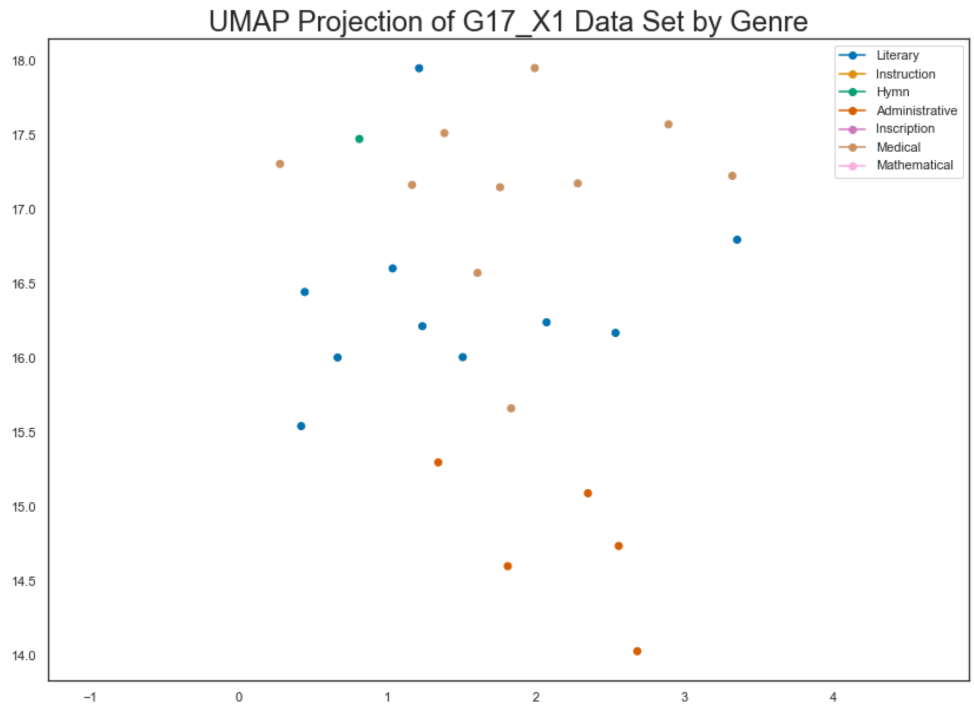

UMAP Projection of F31 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
9.5
9.0
8.5
8.0
7.5
17.0
17.5
18.0
18.5
19.0
19.5
20.0

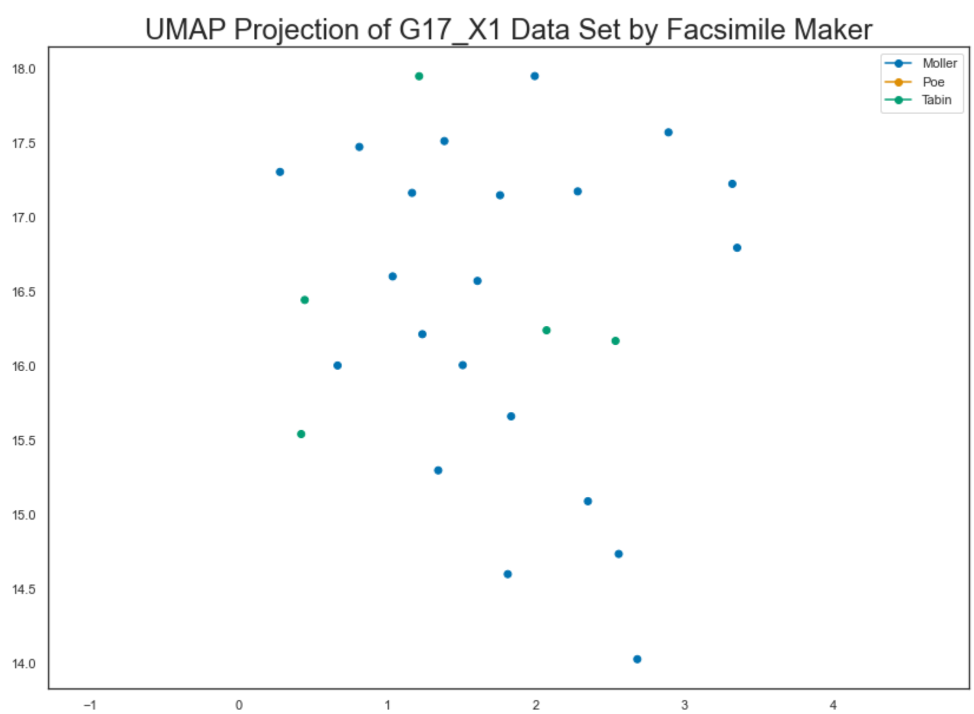

UMAP Projection of G1 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
8
7
6
5
4
3
7
8
9
10
11
12
13
14

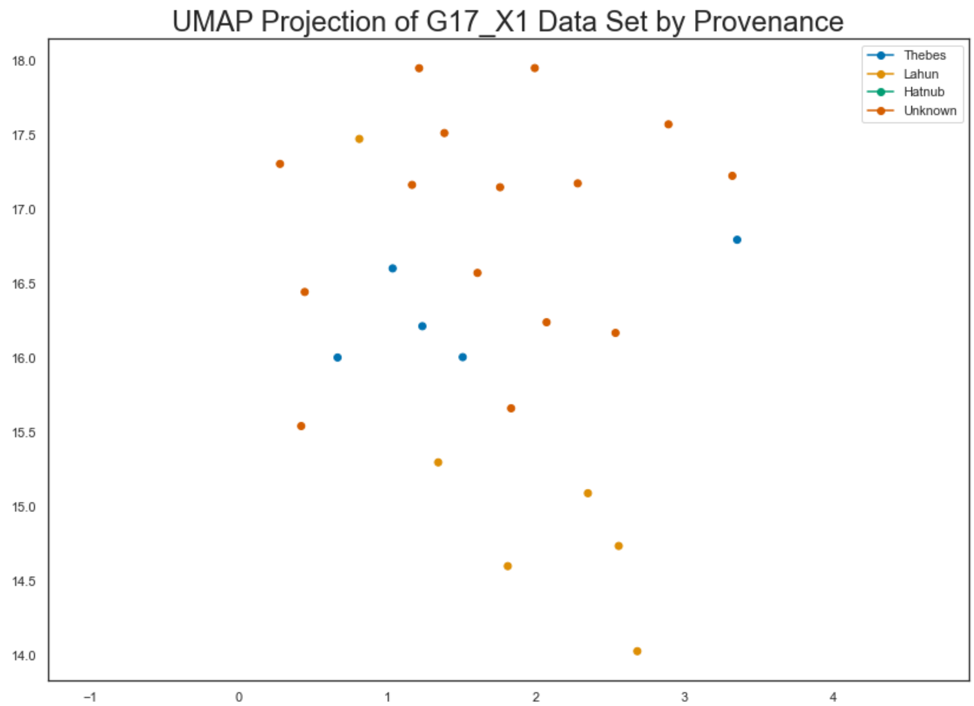

UMAP Projection of G1 Data Set by Facsimile Maker
Moller
Poe
Tabin
8
7
6
5
4
3
7
8
9
10
11
12
13
14

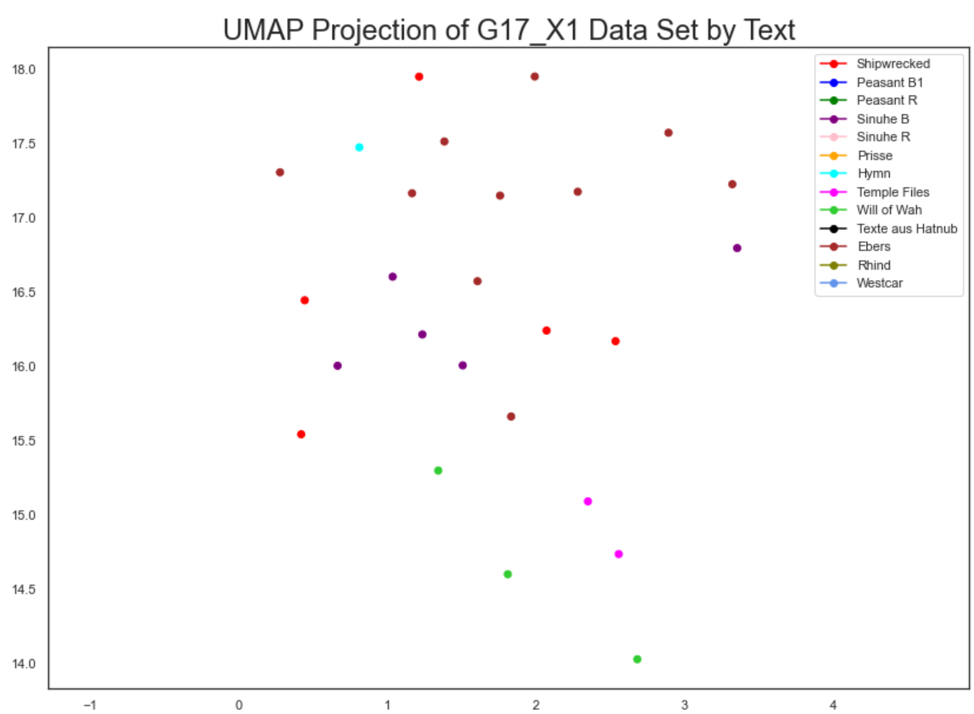

UMAP Projection of G1 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
3
4
5
6
7
8
7
8
9
10
11
12
13
14

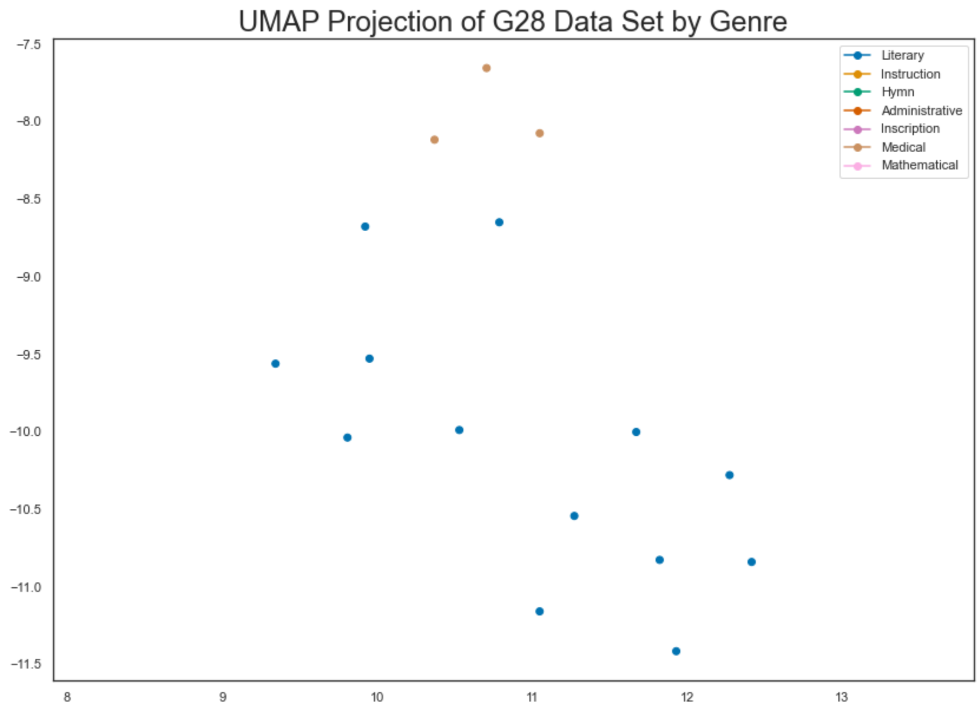

UMAP Projection of G1 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
3
4
5
6
7
8
7
8
9
10
11
12
13
14

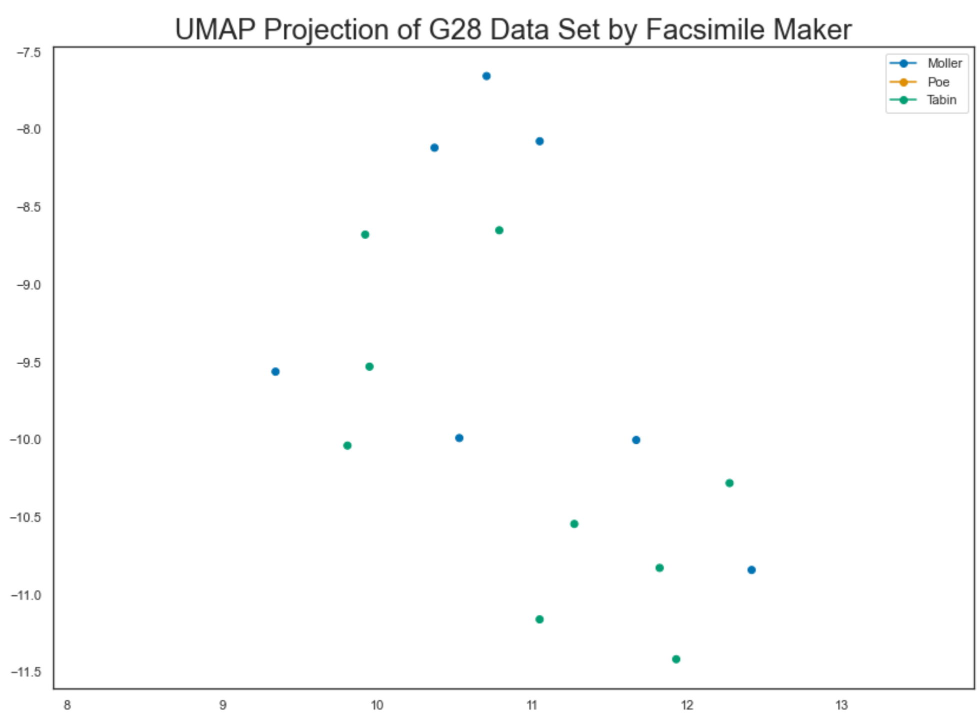

UMAP Projection of G17_X1 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
−1
0
1
2
3
4

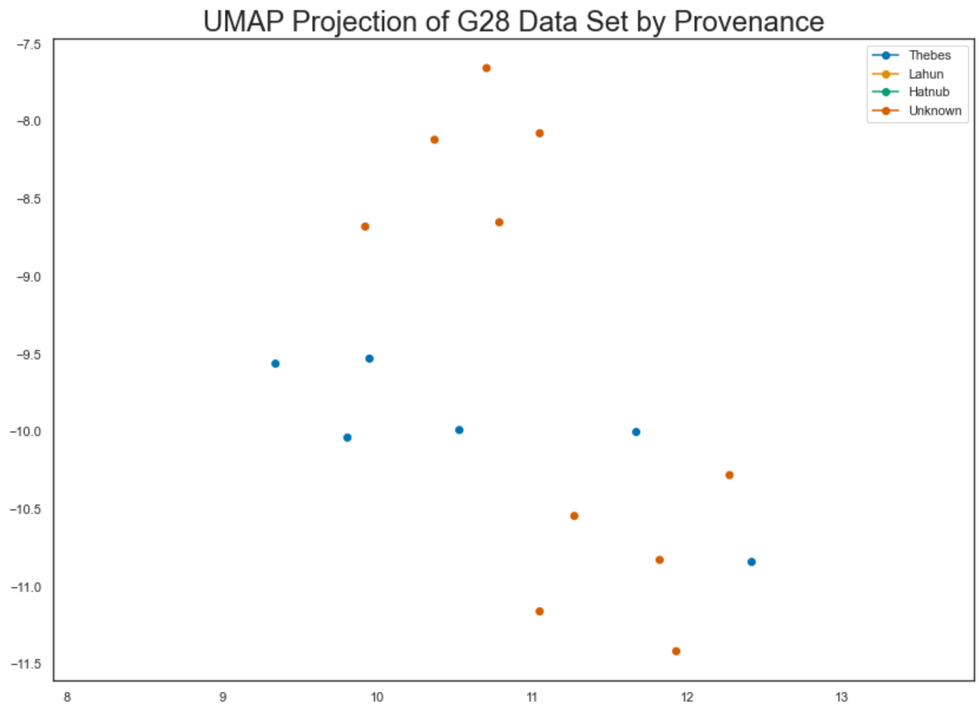

UMAP Projection of G17_X1 Data Set by Facsimile Maker
Moller
Poe
Tabin
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
−1
0
1
2
3
4

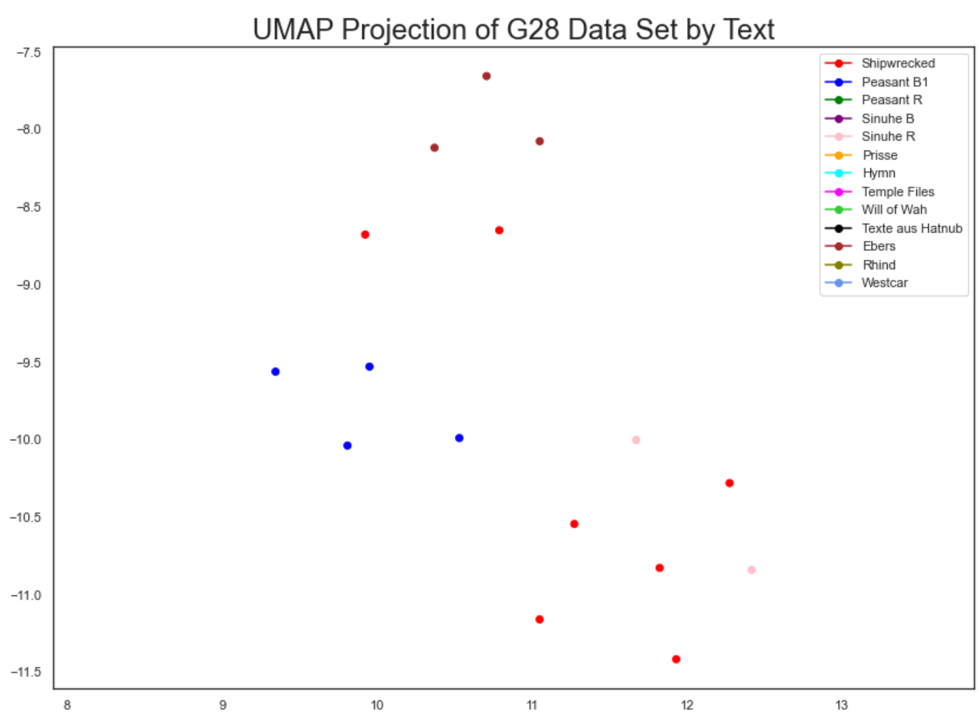

UMAP Projection of G17_X1 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
−1
0
1
2
3
4

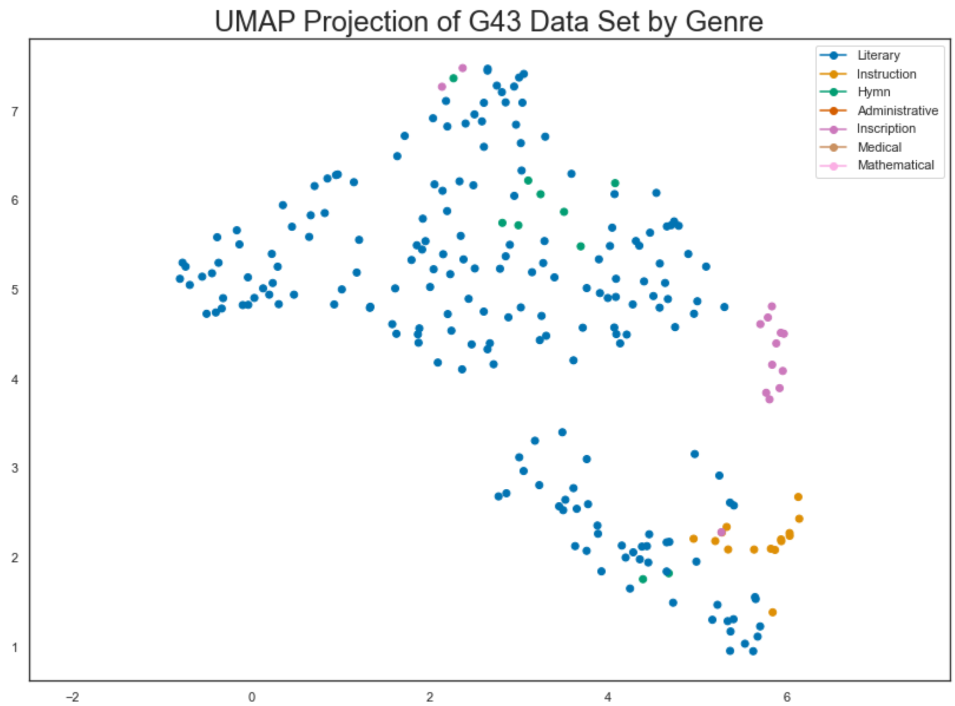

UMAP Projection of G17_X1 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
−1
0
1
2
3
4

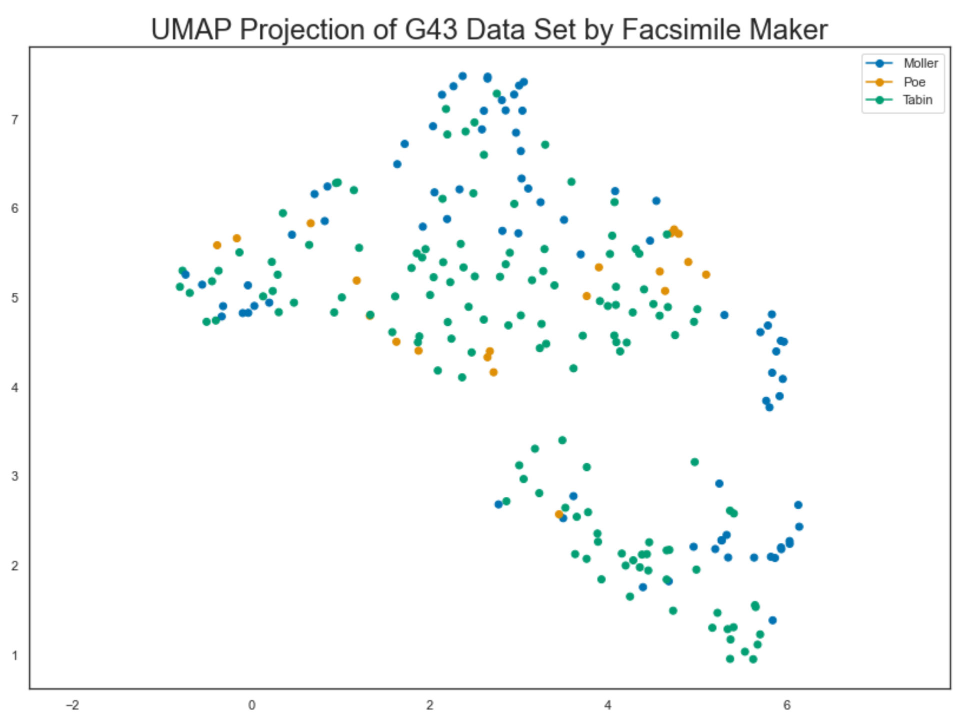

UMAP Projection of G28 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
−7.5
−8.0
−8.5
−9.0
−9.5
−10.0
−10.5
−11.0
−11.5
8
9
10
11
12
13

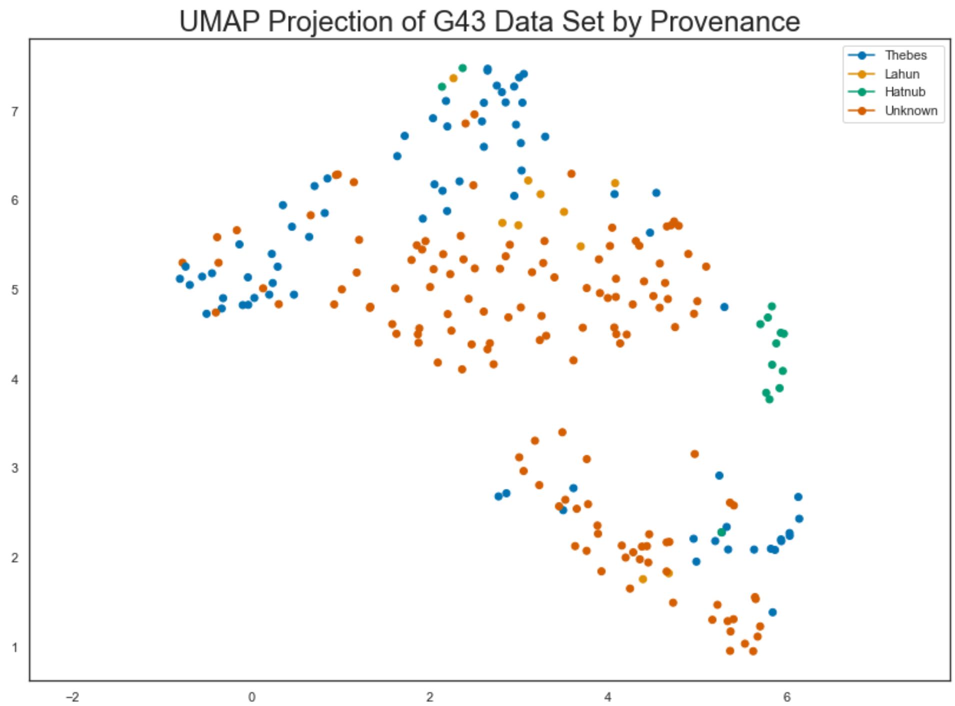

UMAP Projection of G28 Data Set by Facsimile Maker
Moller
Poe
Tabin
−7.5
−8.0
−8.5
−9.0
−9.5
−10.0
−10.5
−11.0
−11.5
8
9
10
11
12
13

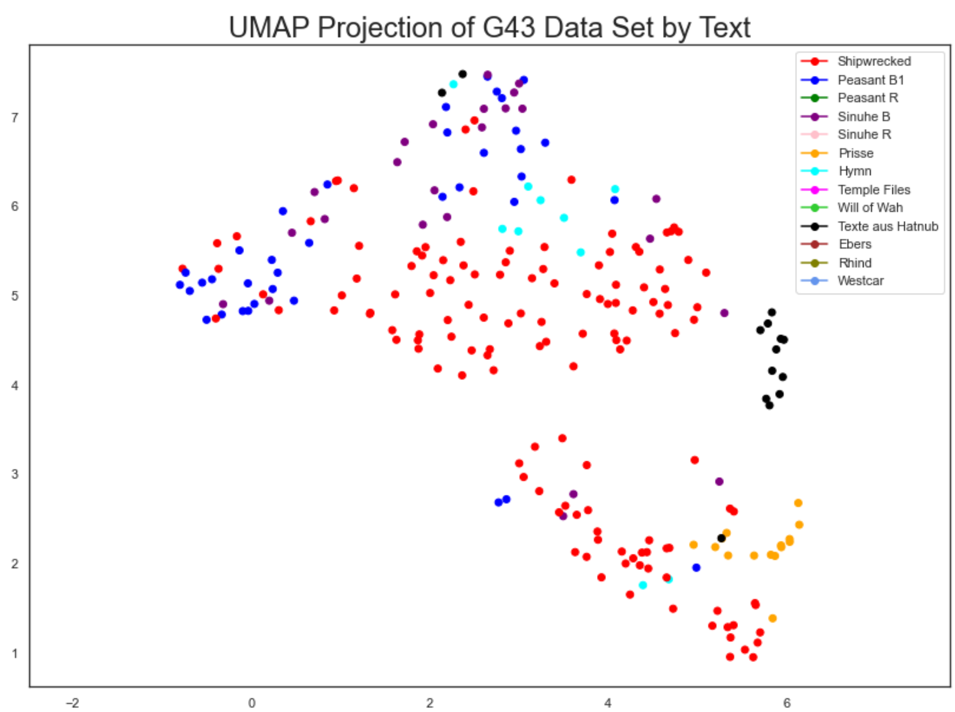

UMAP Projection of G28 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
-11.5
8
9
10
11
12
13

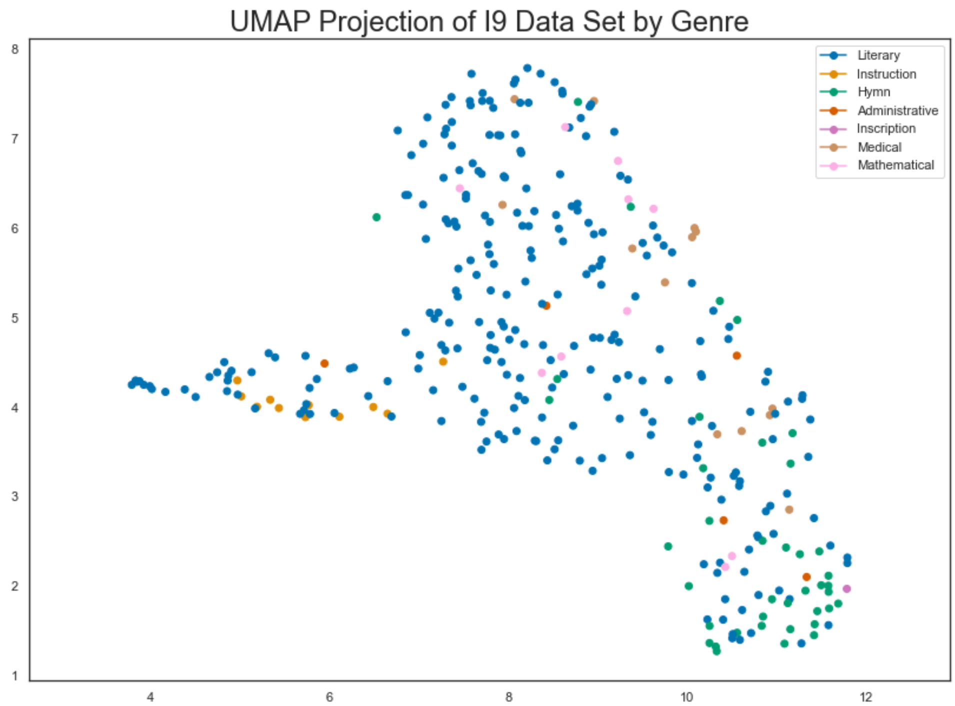

UMAP Projection of G28 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
-11.5
8
9
10
11
12
13

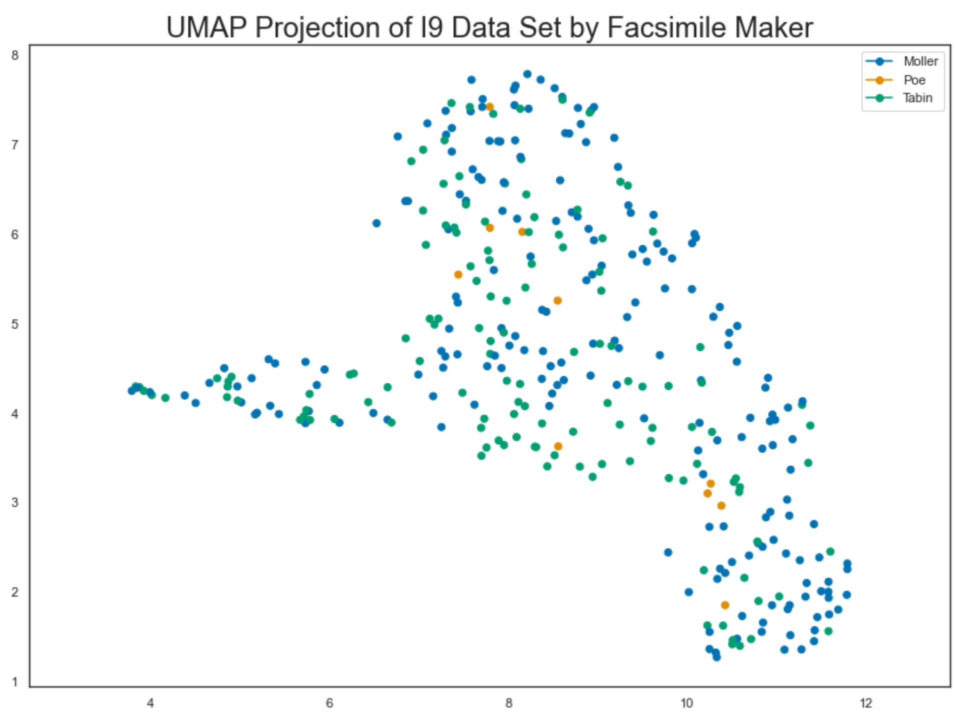

UMAP Projection of G43 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
1
2
3
4
5
6
7
−2
0
2
4
6

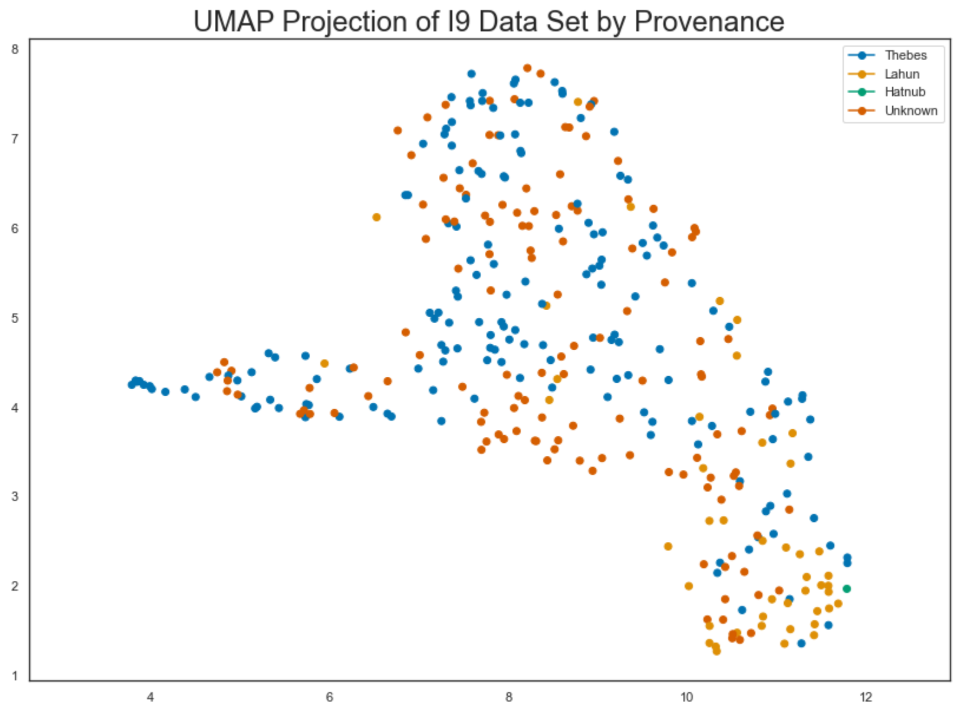

UMAP Projection of G43 Data Set by Facsimile Maker
Moller
Poe
Tabin
1
2
3
4
5
6
7
−2
0
2
4
6


UMAP Projection of G43 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
7
6
5
4
3
2
1
−2
0
2
4
6

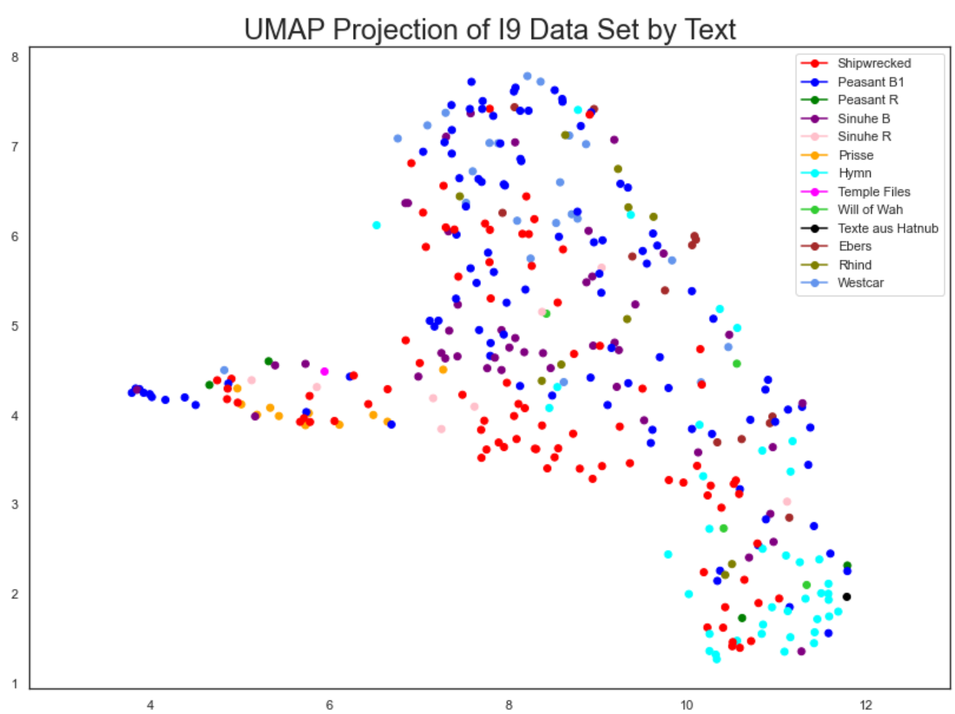

UMAP Projection of G43 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
7
6
5
4
3
2
1
−2
0
2
4
6


UMAP Projection of I9 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
1
2
3
4
5
6
7
8
4
6
8
10
12

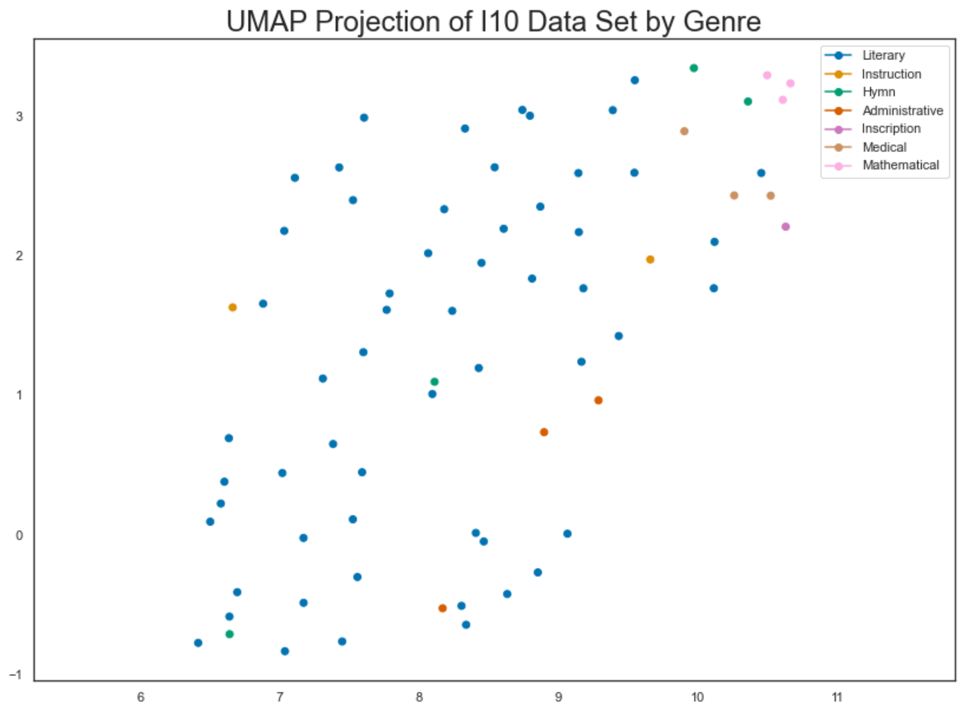

UMAP Projection of I9 Data Set by Facsimile Maker
Moller
Poe
Tabin
1
2
3
4
5
6
7
8
4
6
8
10
12

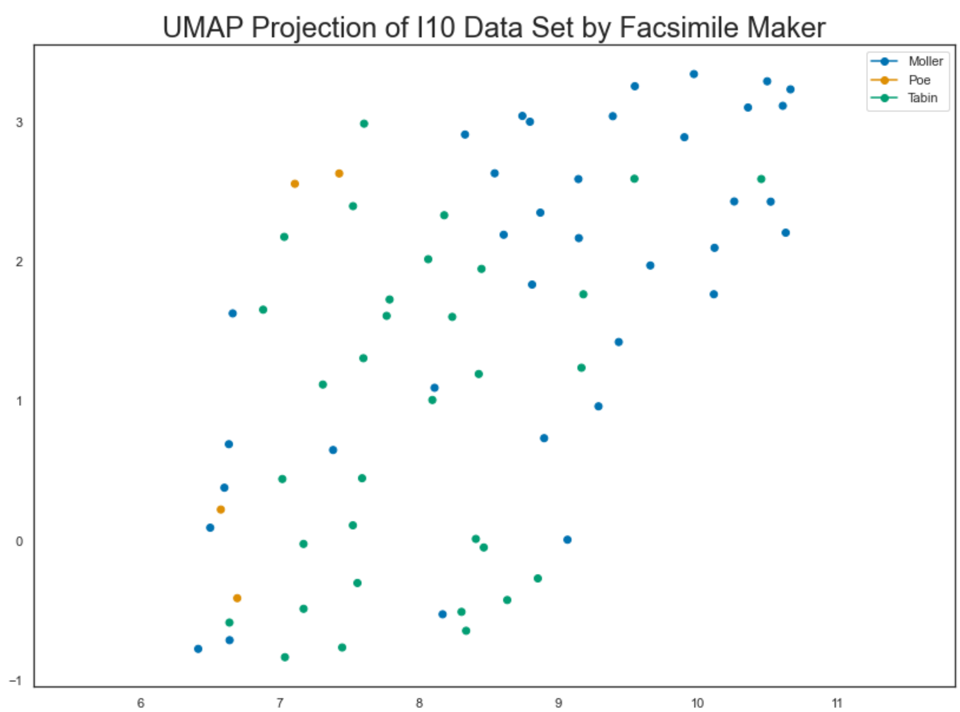


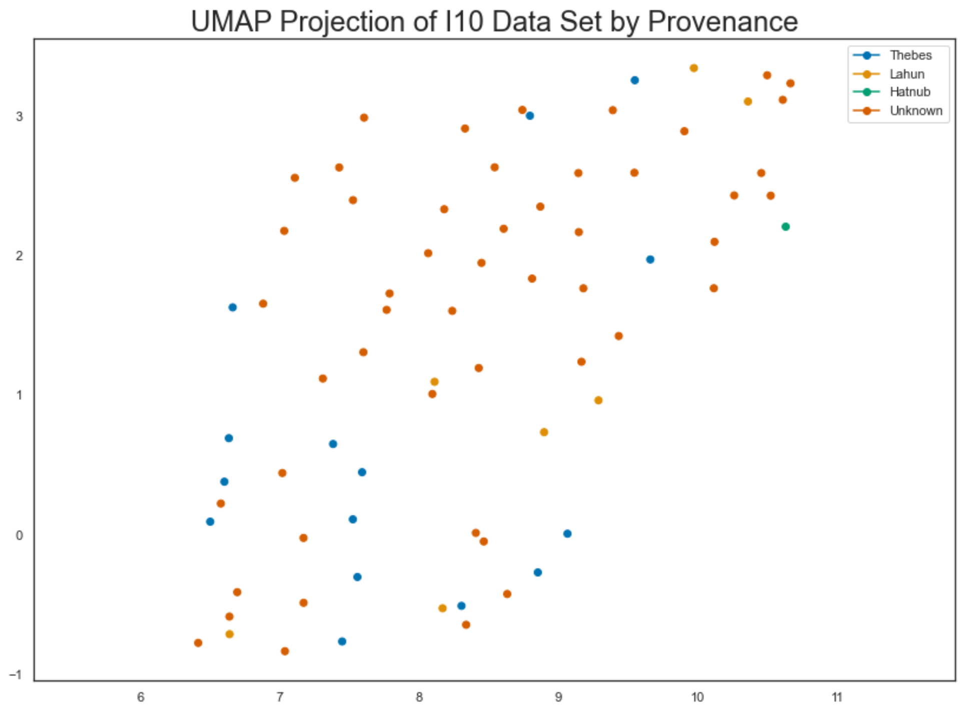
UMAP Projection of I9 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown

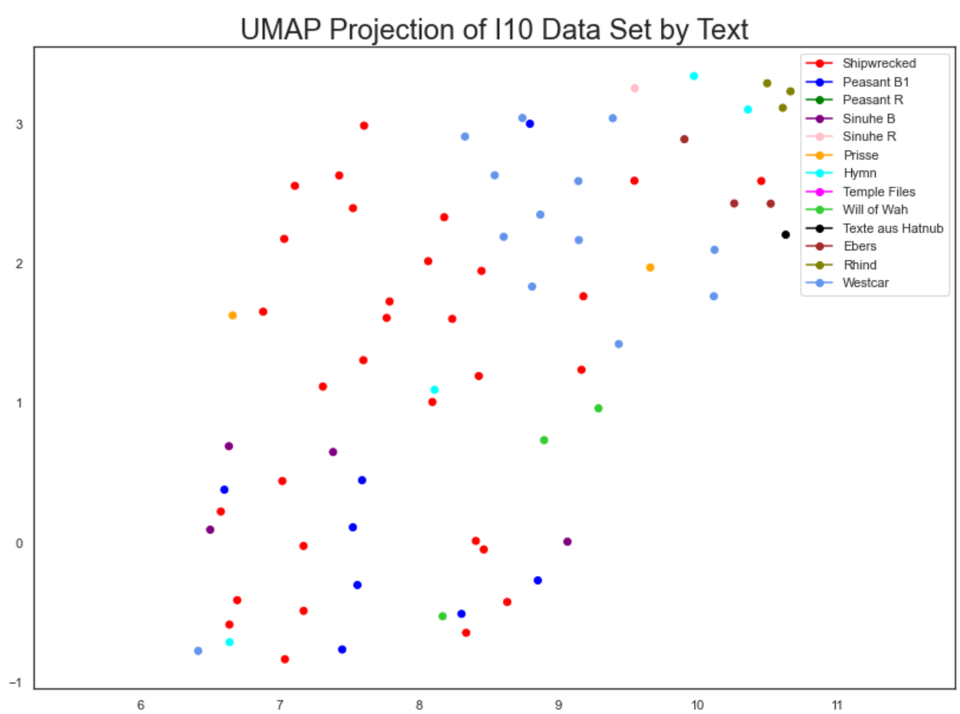


UMAP Projection of I9 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar

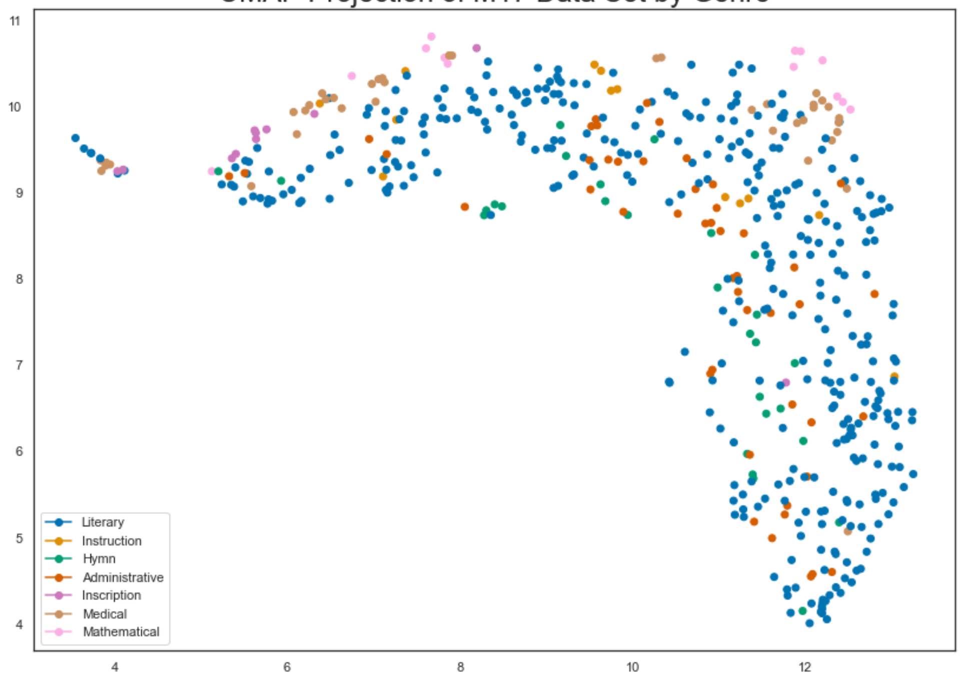

UMAP Projection of I10 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
3
2
1
0
−1
6
7
8
9
10
11


UMAP Projection of I10 Data Set by Facsimile Maker
Moller
Poe
Tabin
3
2
1
0
−1
6
7
8
9
10
11

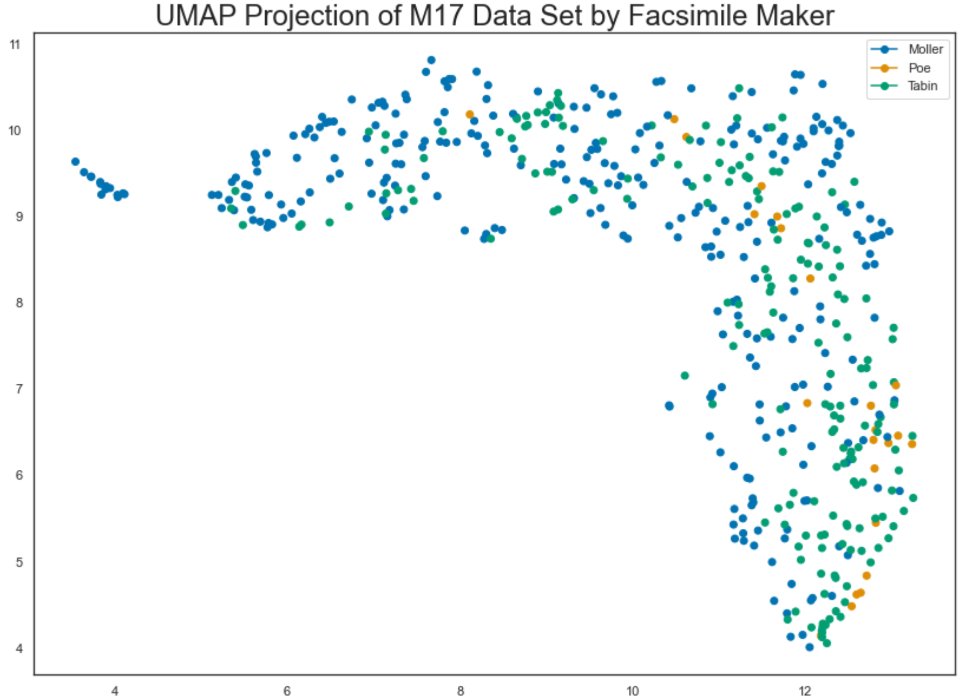

UMAP Projection of I10 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
3
2
1
0
−1
6
7
8
9
10
11

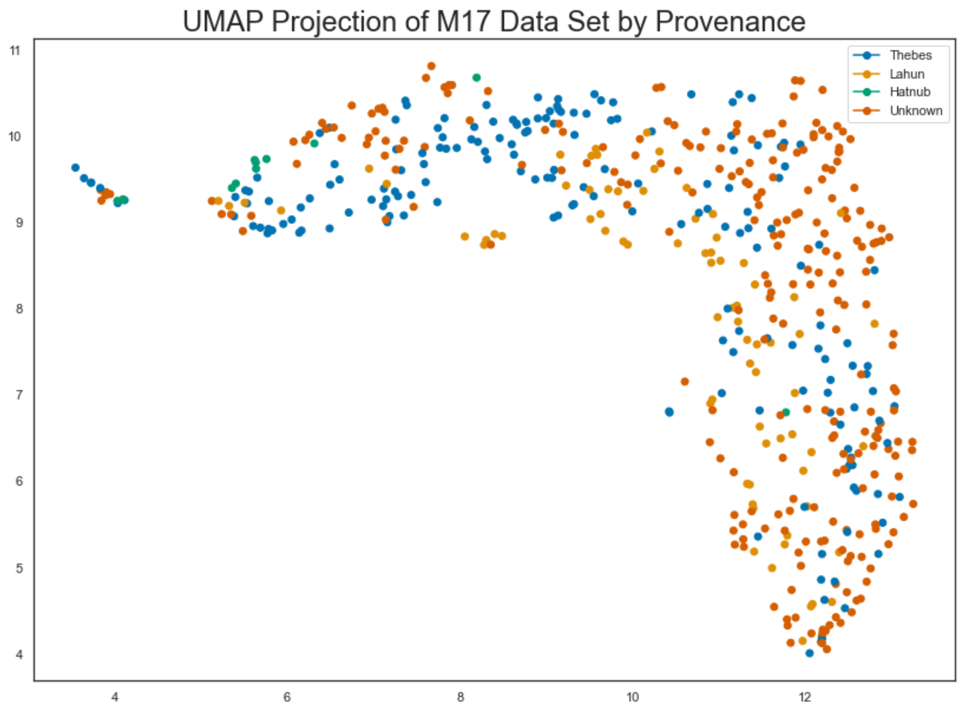

UMAP Projection of I10 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
3
2
1
0
−1
6
7
8
9
10
11

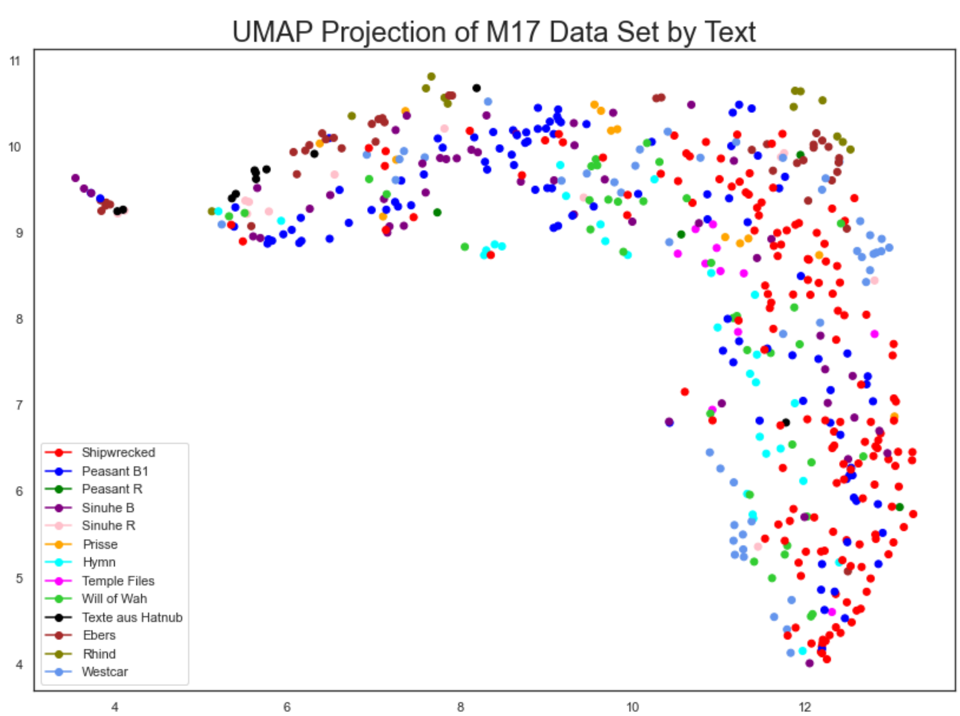
UMAP Projection of M17 Data Set by Genre

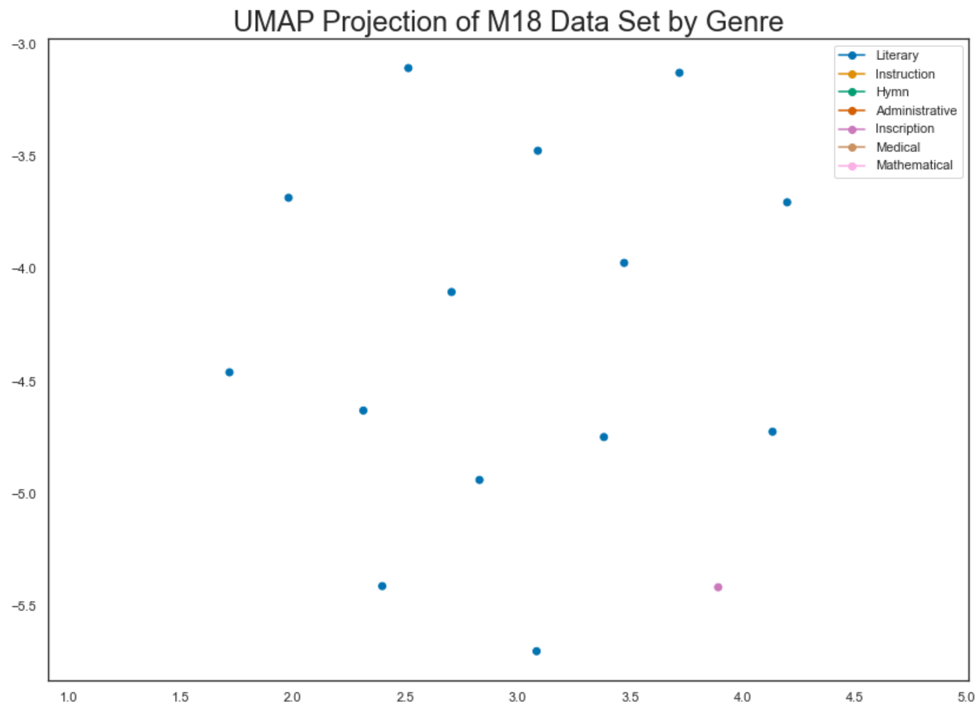


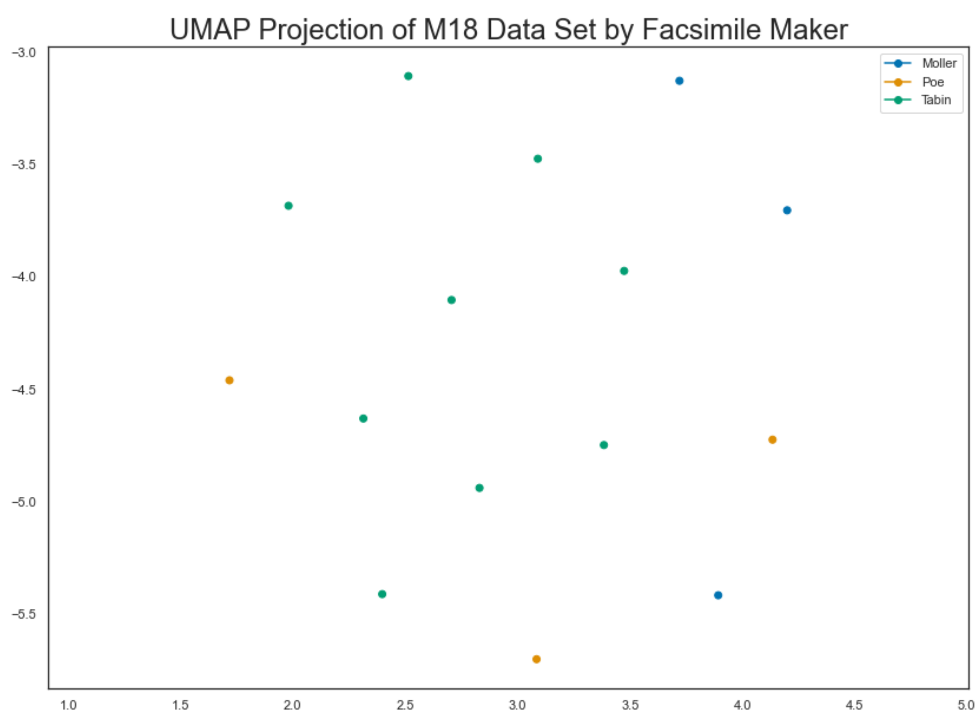
UMAP Projection of M17 Data Set by Facsimile Maker

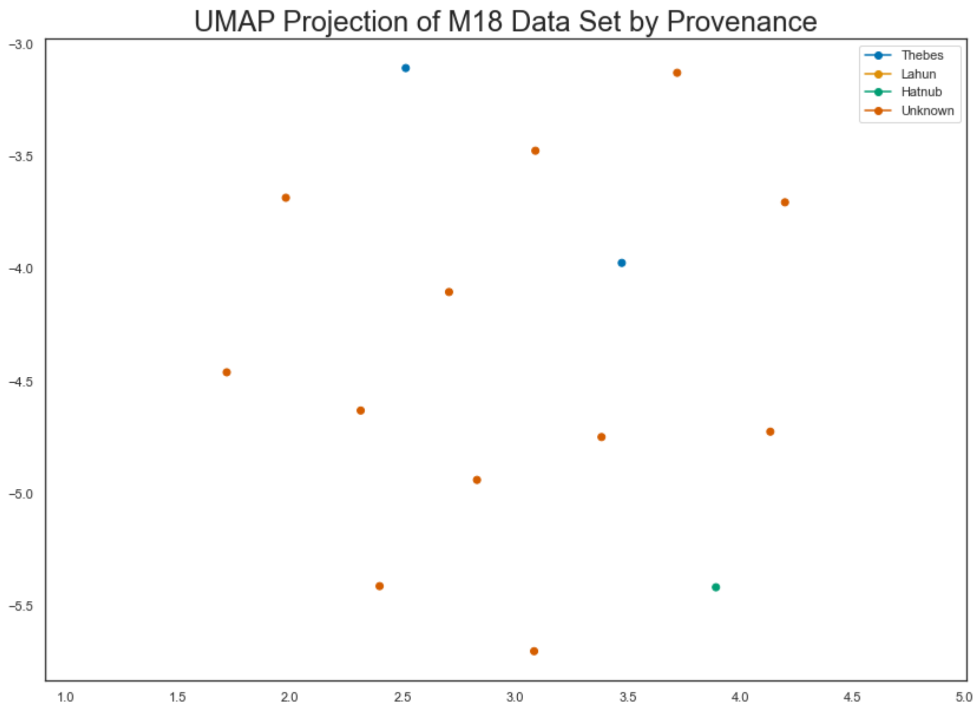


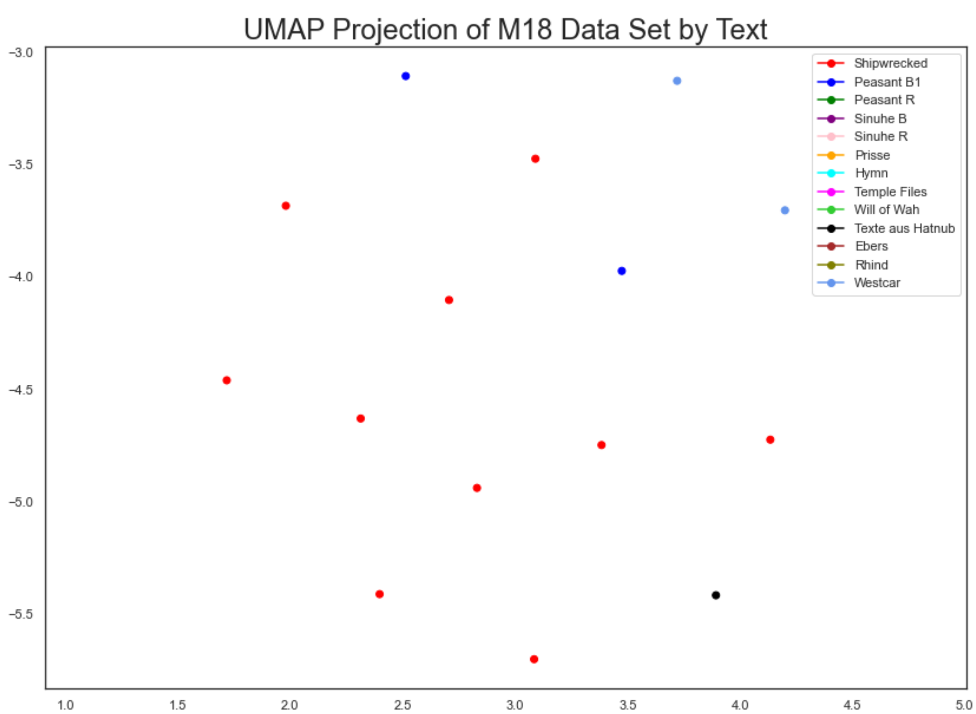

UMAP Projection of M17 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
11
10
9
8
7
6
5
4
4
6
8
10
12

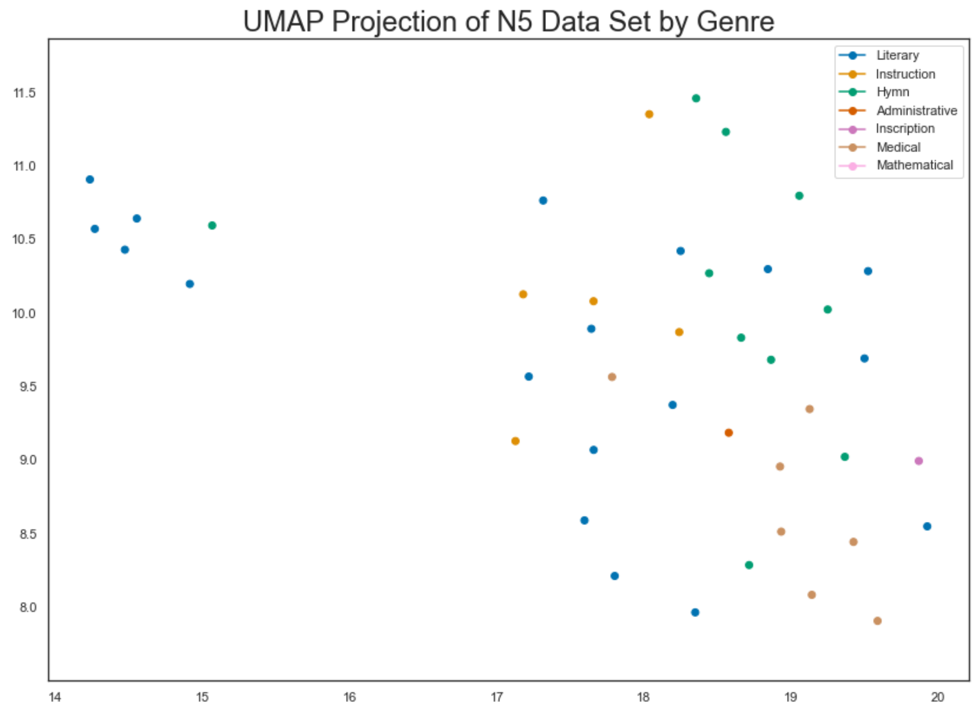

UMAP Projection of M17 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
11
10
9
8
7
6
5
4
4
6
8
10
12

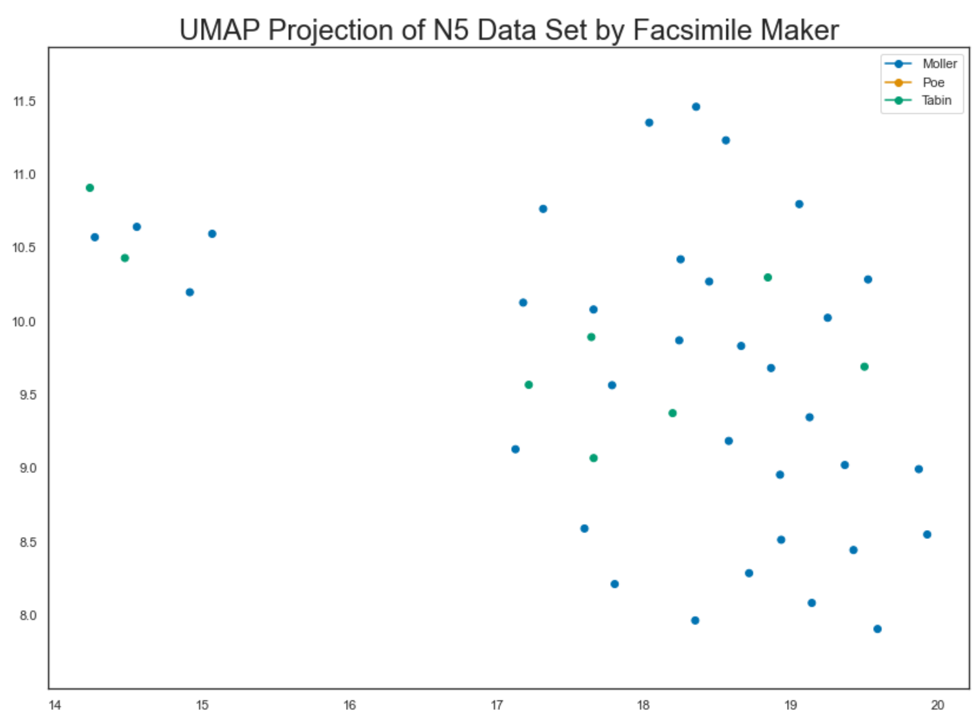

UMAP Projection of M18 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
-3.0
-3.5
-4.0
-4.5
-5.0
-5.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

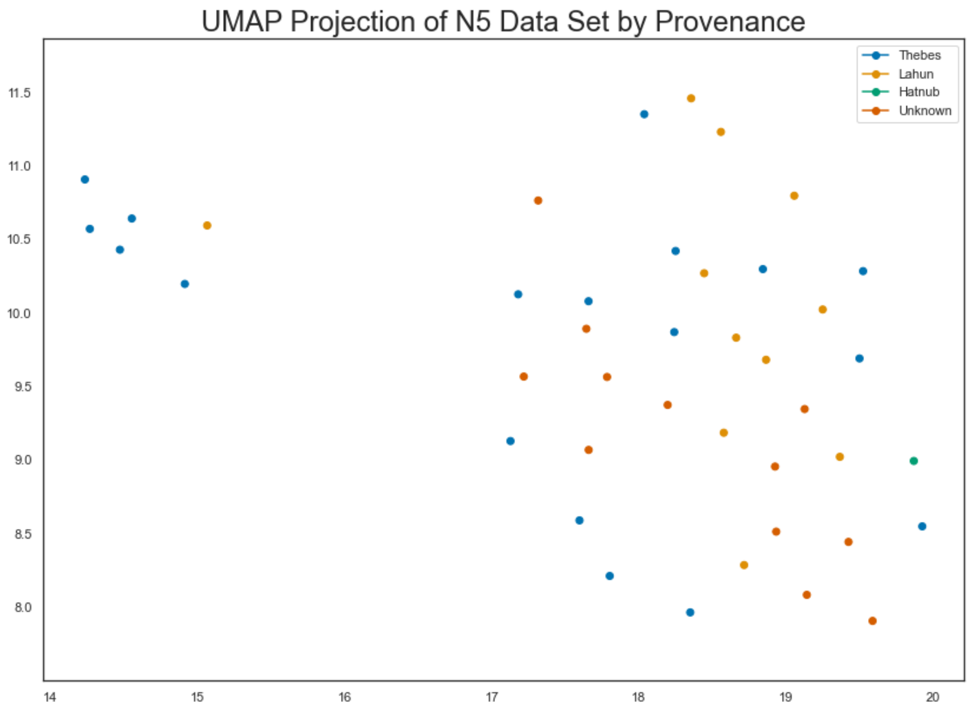

UMAP Projection of M18 Data Set by Facsimile Maker
Moller
Poe
Tabin
-3.0
-3.5
-4.0
-4.5
-5.0
-5.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

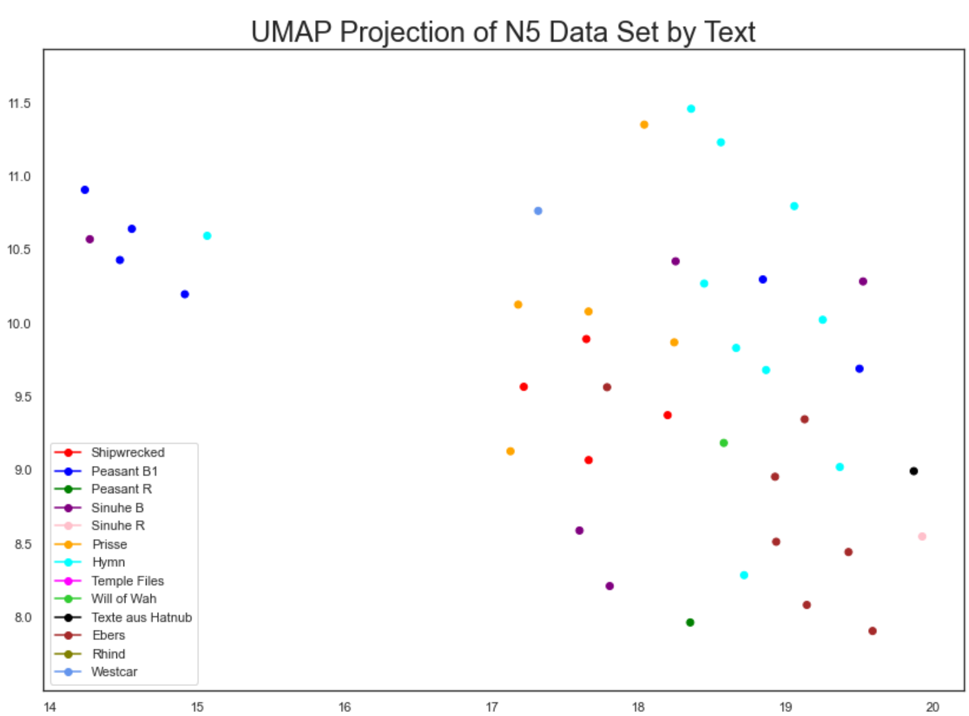

UMAP Projection of M18 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
-3.0
-3.5
-4.0
-4.5
-5.0
-5.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

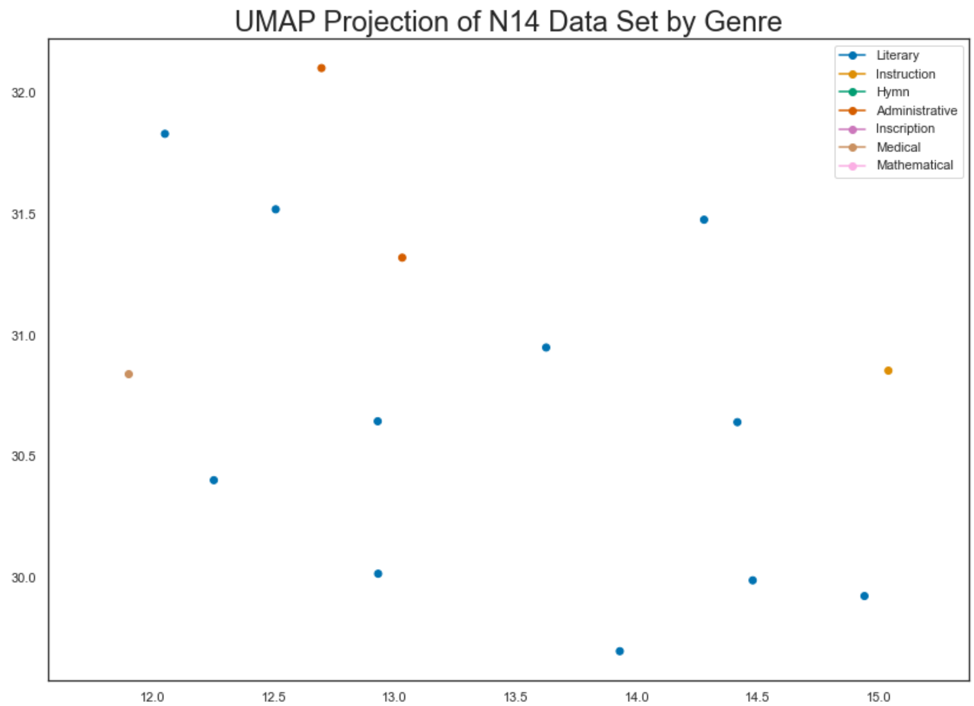

UMAP Projection of M18 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
-3.0
-3.5
-4.0
-4.5
-5.0
-5.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

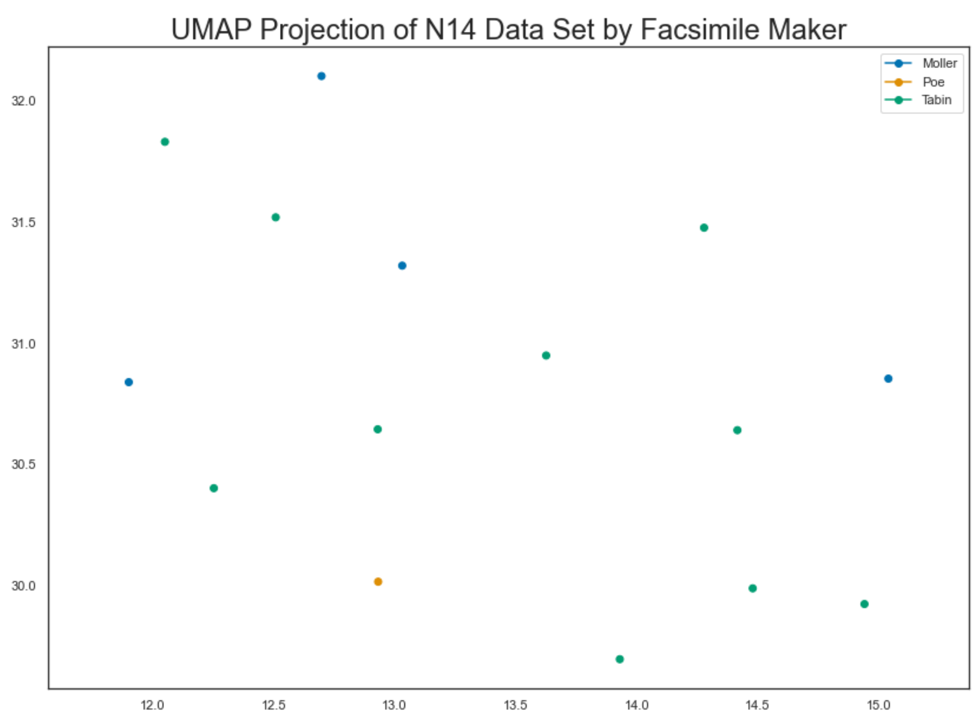

UMAP Projection of N5 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
14
15
16
17
18
19
20

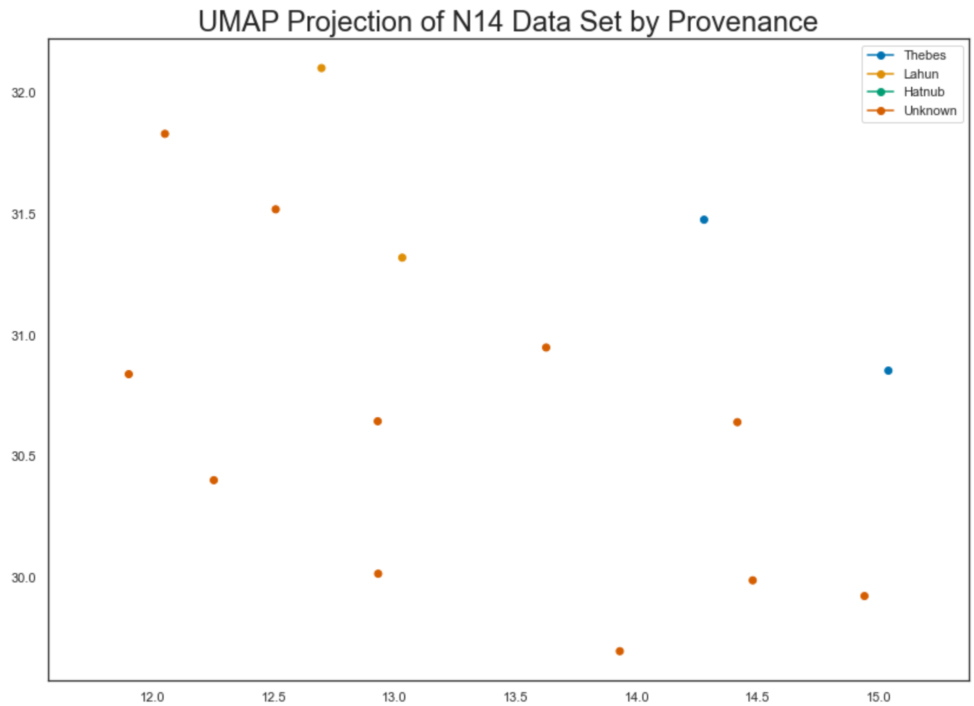

UMAP Projection of N5 Data Set by Facsimile Maker
Moller
Poe
Tabin
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
14
15
16
17
18
19
20

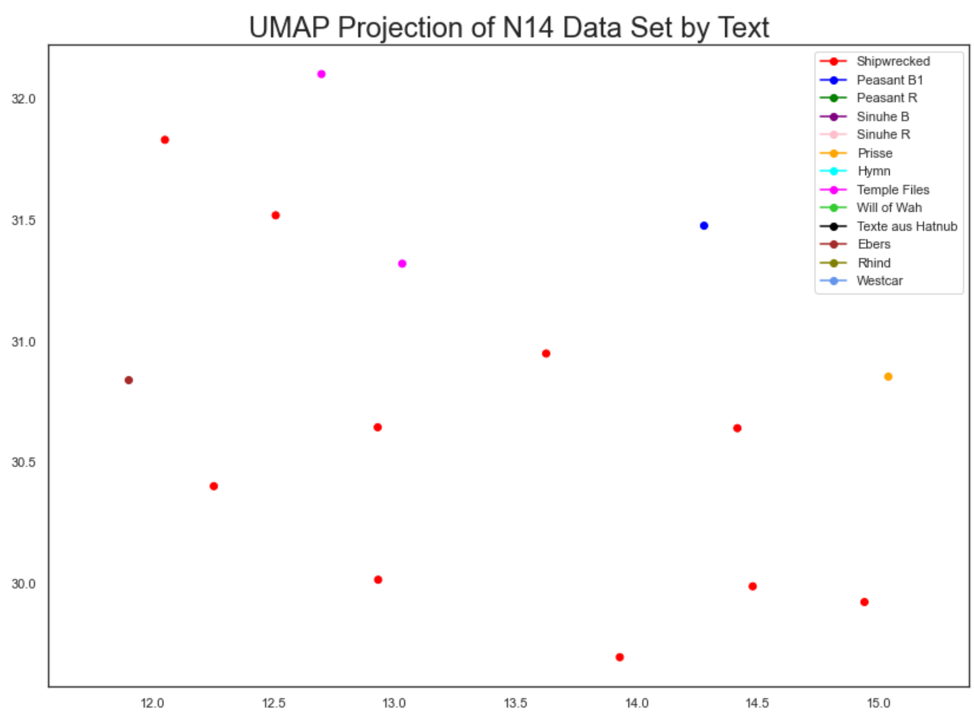

UMAP Projection of N5 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
14
15
16
17
18
19
20

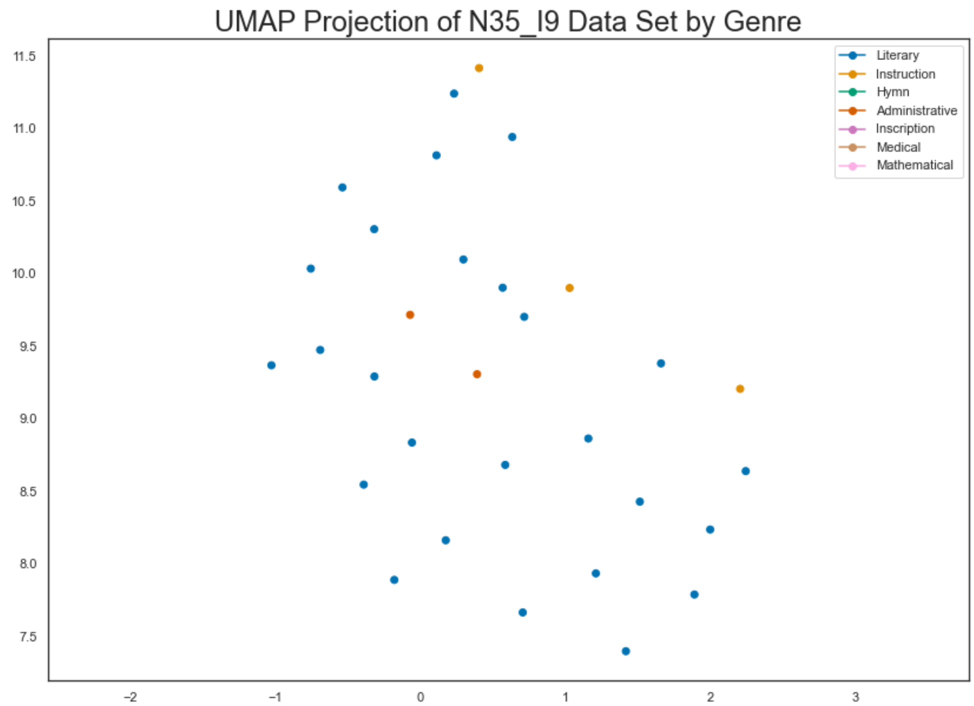

UMAP Projection of N5 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
14
15
16
17
18
19
20

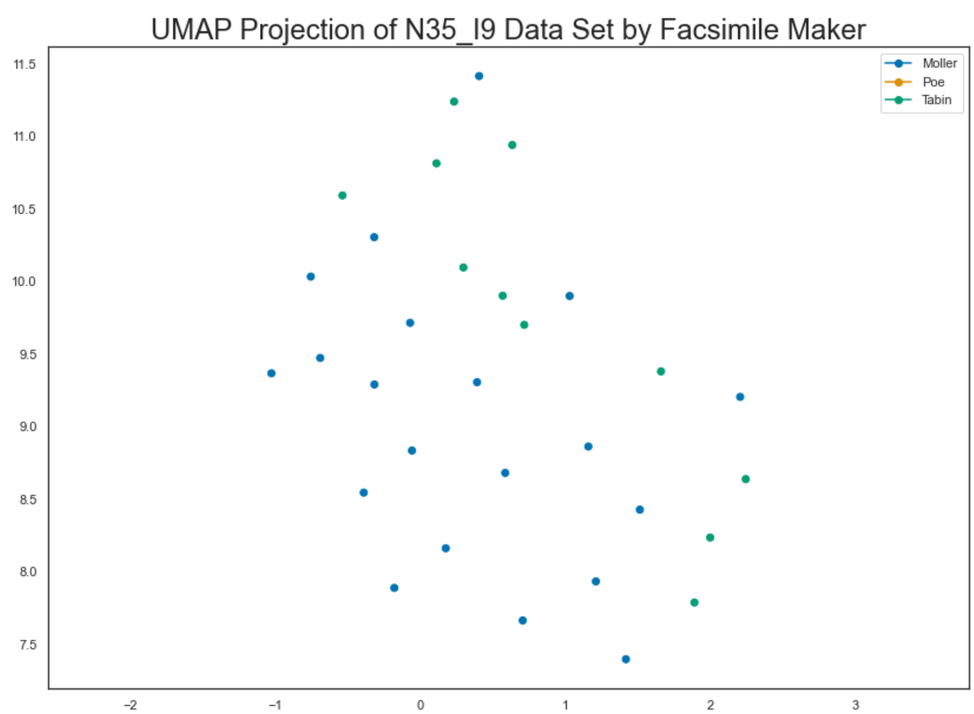

UMAP Projection of N14 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
32.0
31.5
31.0
30.5
30.0
12.0
12.5
13.0
13.5
14.0
14.5
15.0

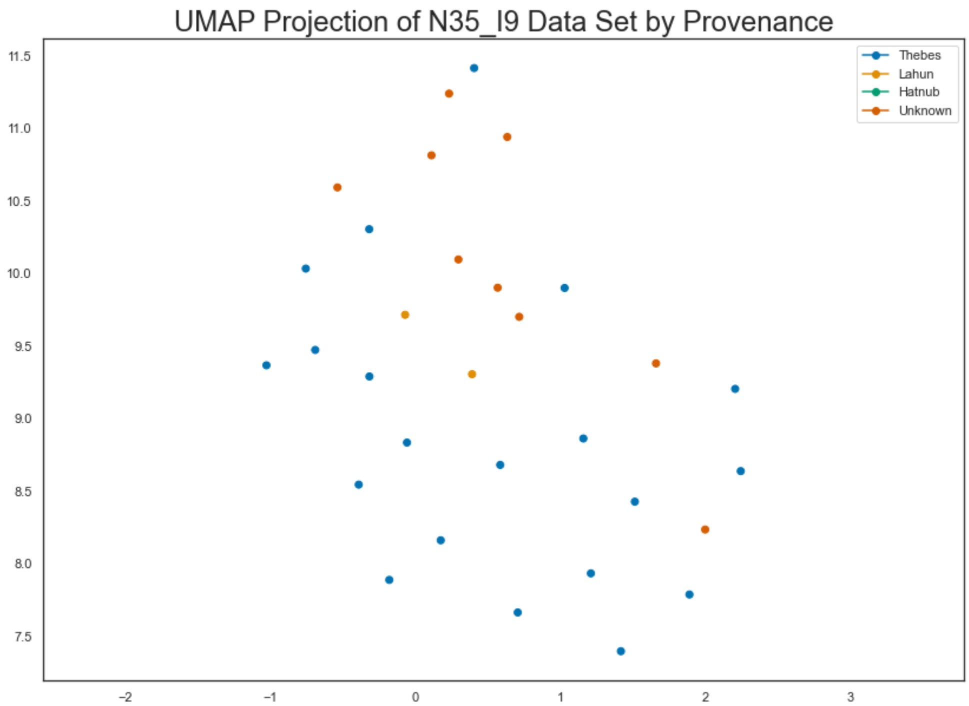

UMAP Projection of N14 Data Set by Facsimile Maker
Moller
Poe
Tabin
32.0
31.5
31.0
30.5
30.0
12.0
12.5
13.0
13.5
14.0
14.5
15.0

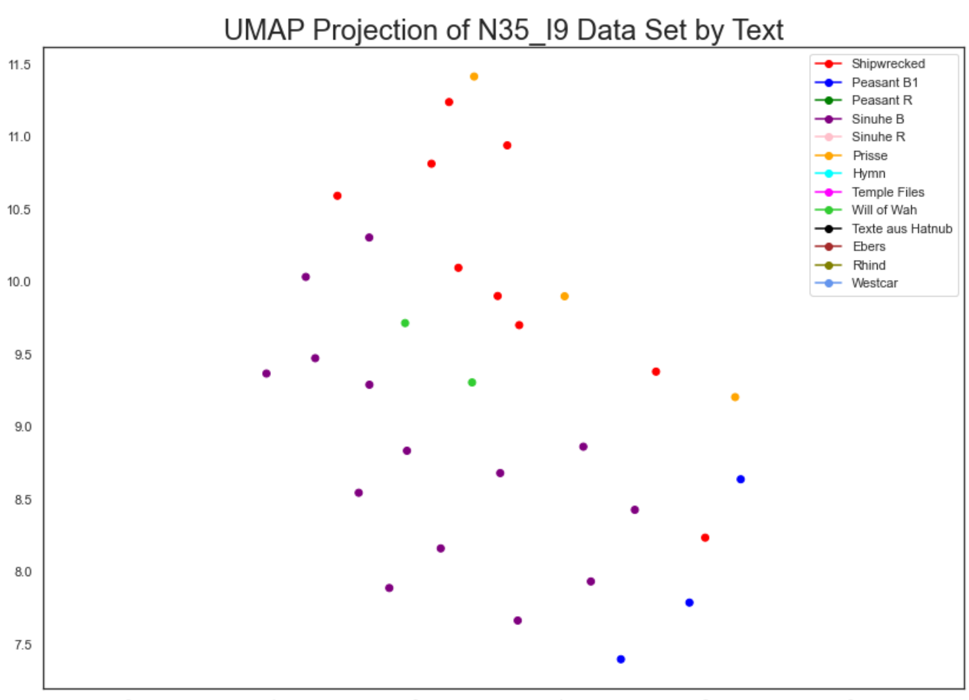

UMAP Projection of N14 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
32.0
31.5
31.0
30.5
30.0
12.0
12.5
13.0
13.5
14.0
14.5
15.0

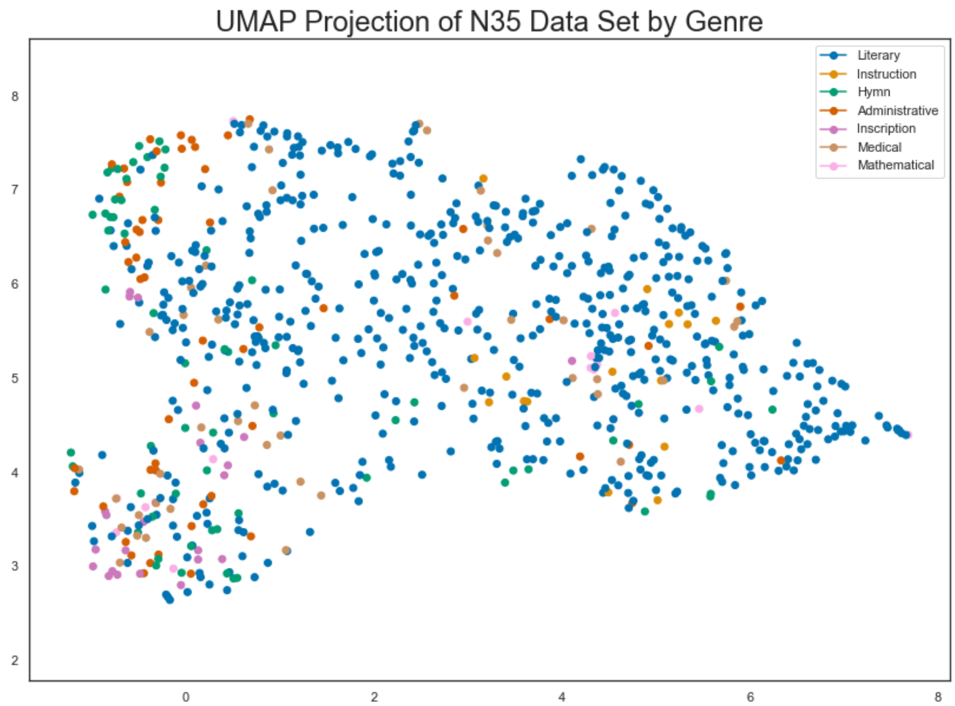

UMAP Projection of N14 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
32.0
31.5
31.0
30.5
30.0
12.0
12.5
13.0
13.5
14.0
14.5
15.0

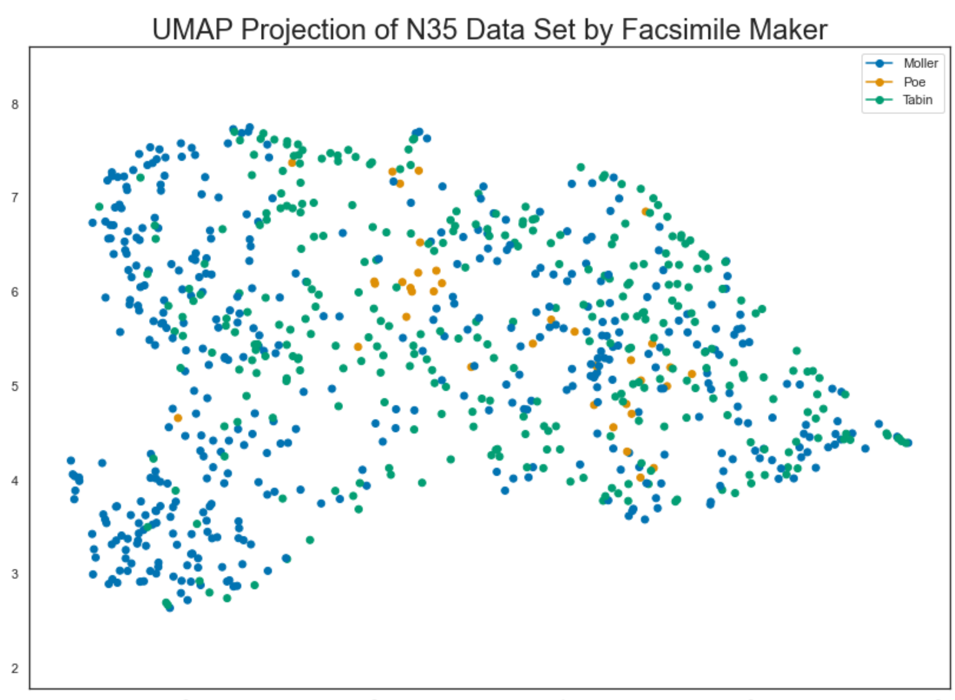

UMAP Projection of N35_I9 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
−2
−1
0
1
2
3

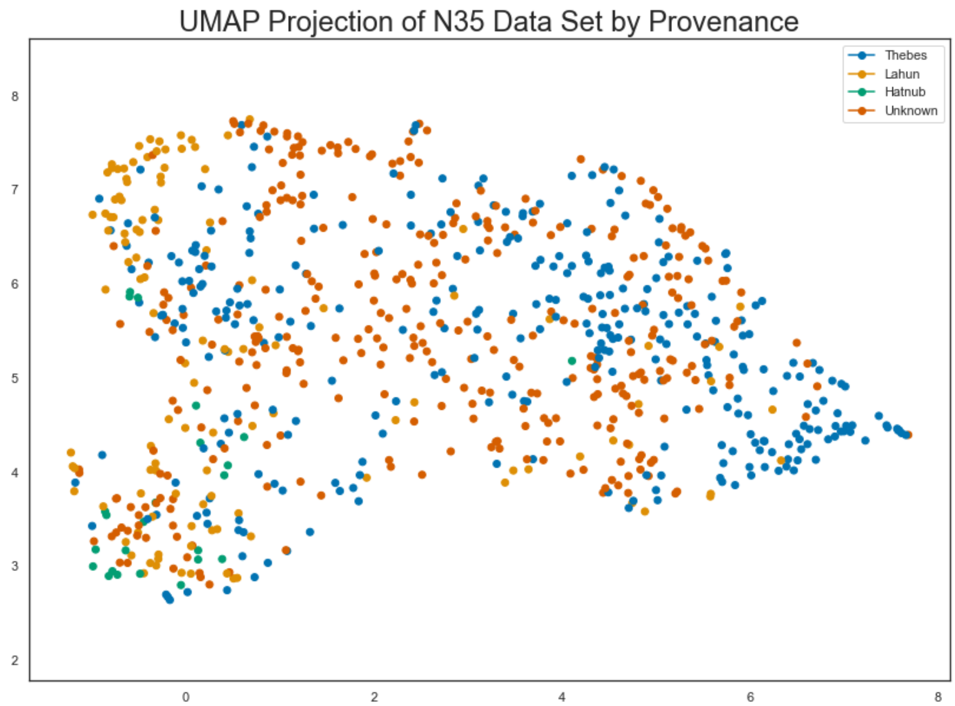

UMAP Projection of N35_I9 Data Set by Facsimile Maker
Moller
Poe
Tabin
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
−2
−1
0
1
2
3

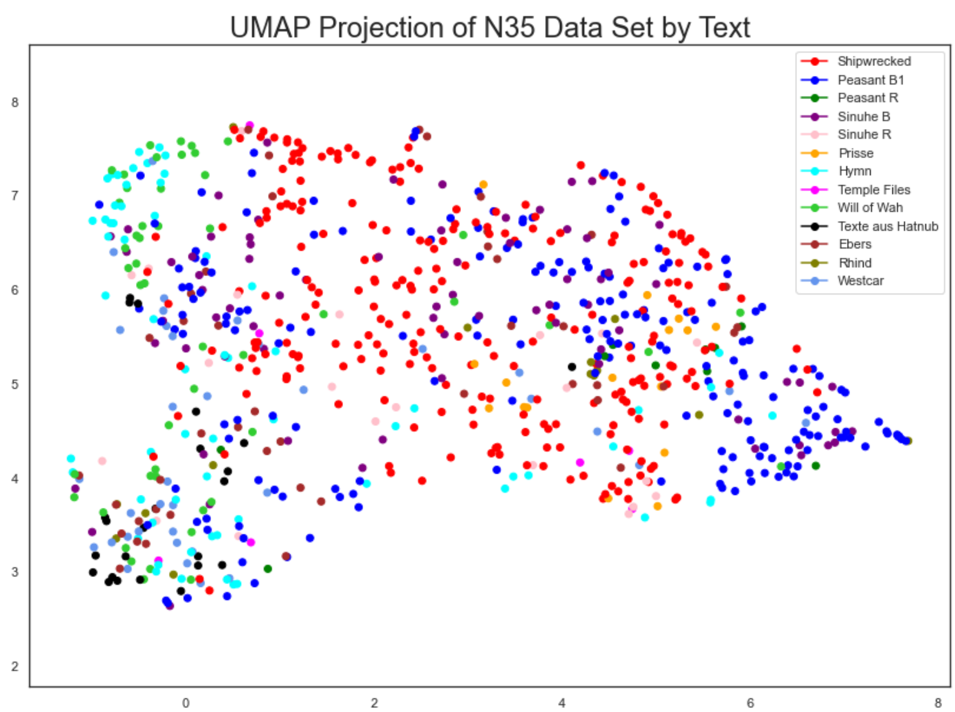

UMAP Projection of N35_I9 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
−2
−1
0
1
2
3

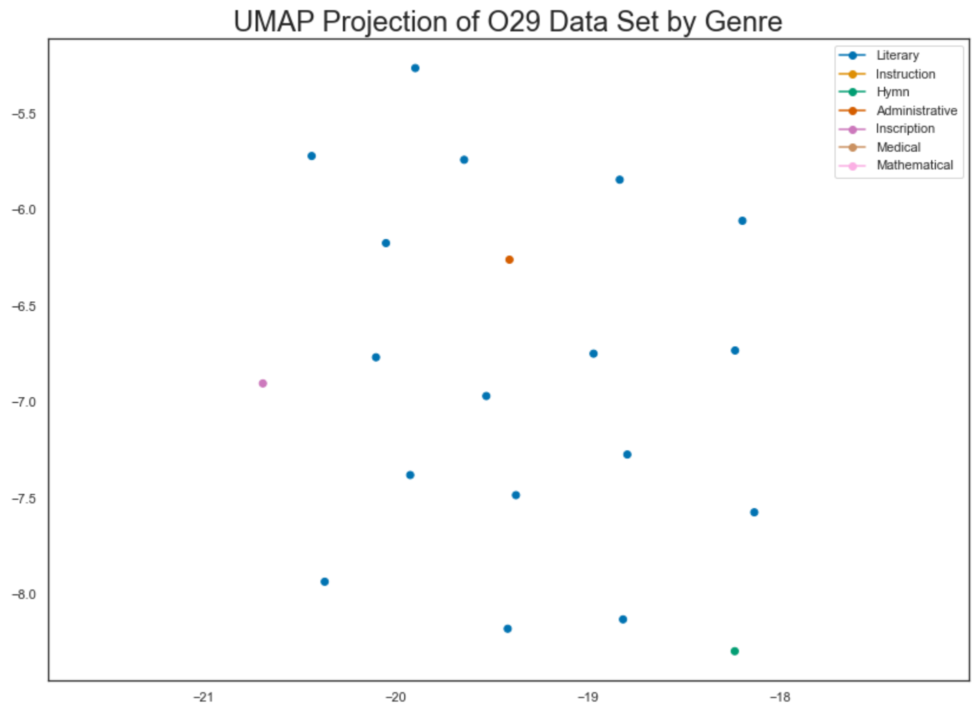

UMAP Projection of N35_I9 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
−2
−1
0
1
2
3

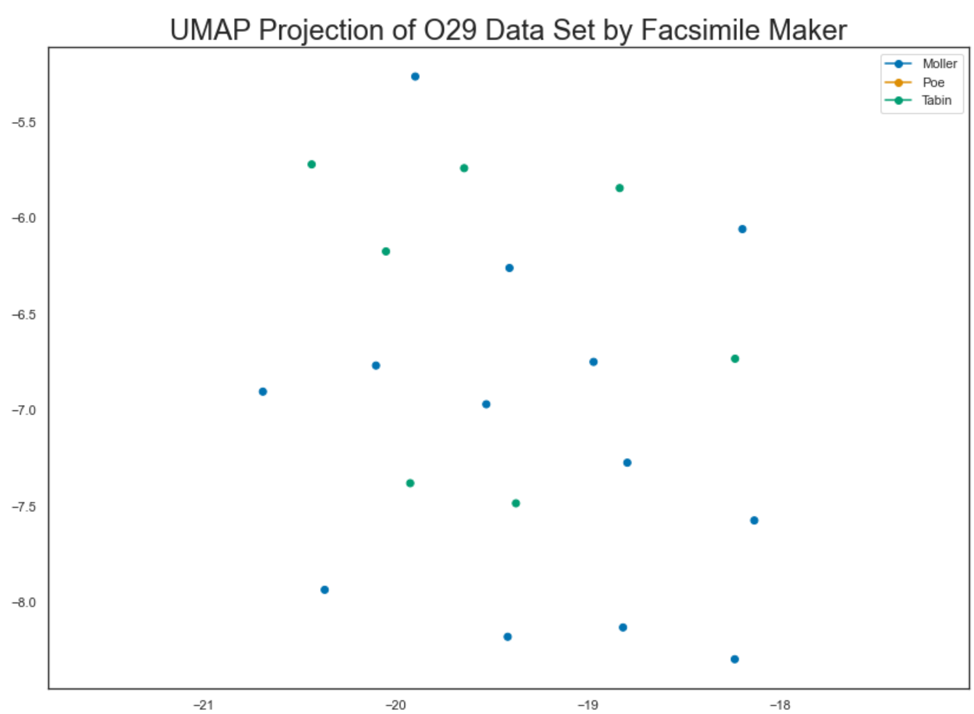

UMAP Projection of N35 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
8
7
6
5
4
3
2
0
2
4
6
8

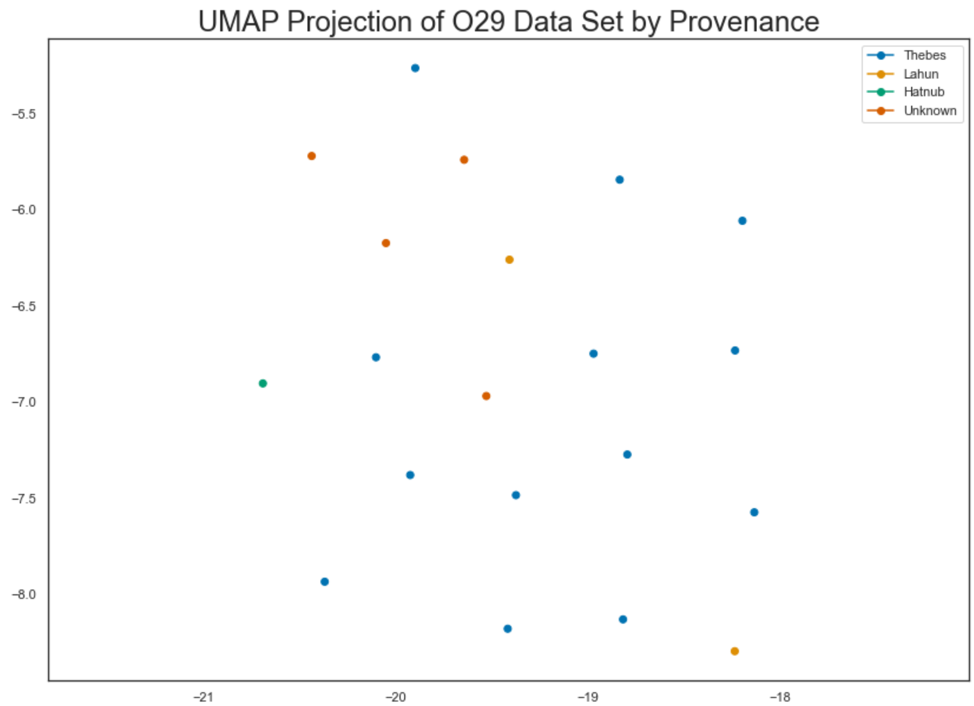

UMAP Projection of N35 Data Set by Facsimile Maker
Moller
Poe
Tabin
8
7
6
5
4
3
2
0
2
4
6
8

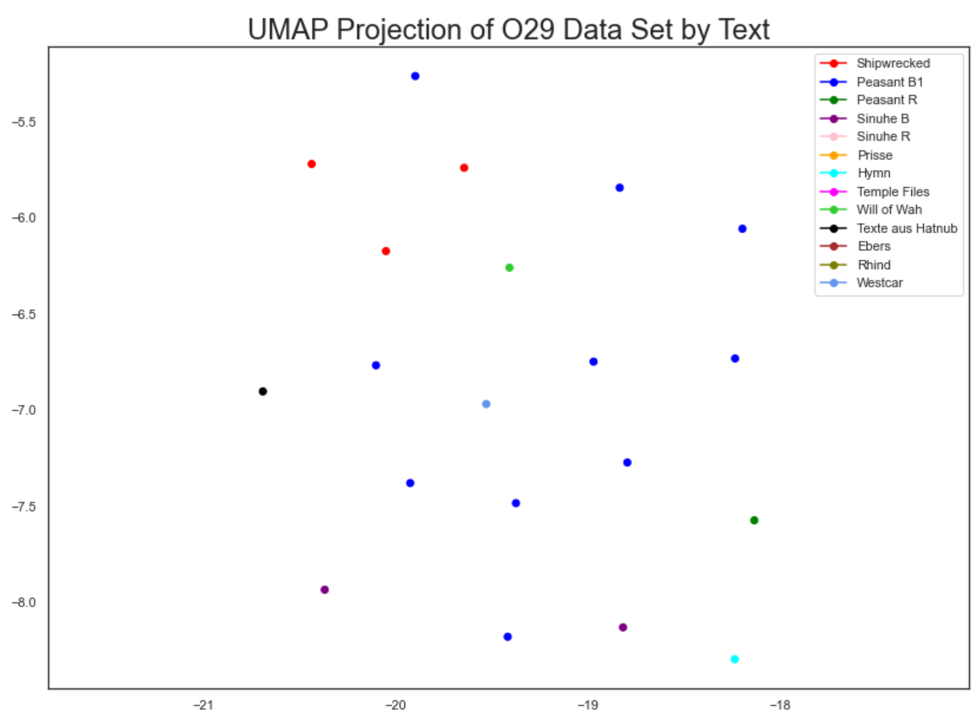

UMAP Projection of N35 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
8
7
6
5
4
3
2
0
2
4
6
8

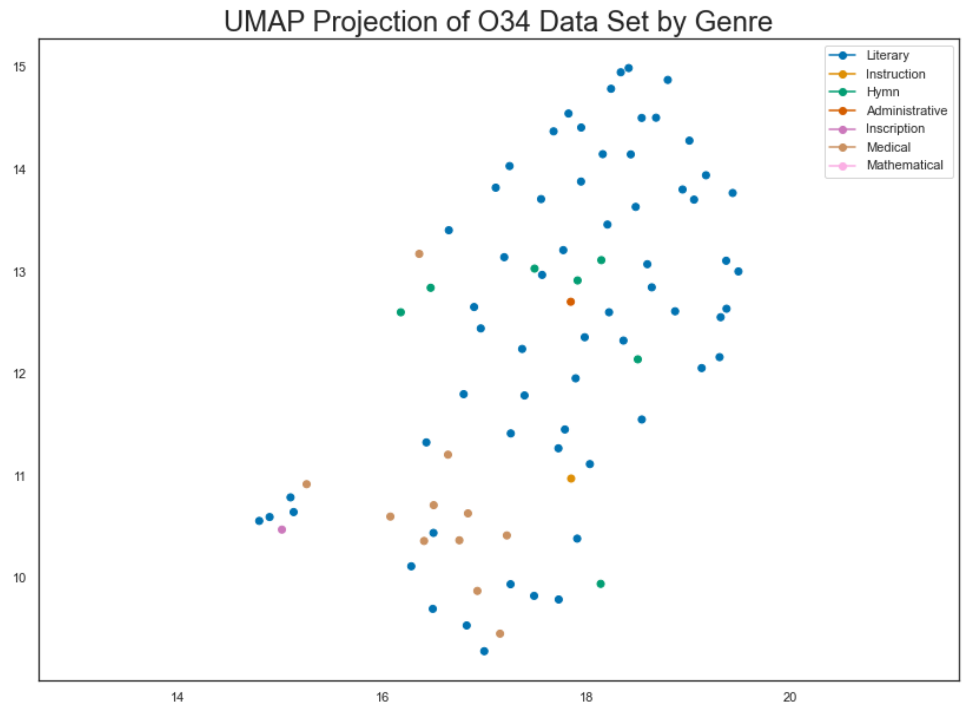

UMAP Projection of N35 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
8
7
6
5
4
3
2
0
2
4
6
8

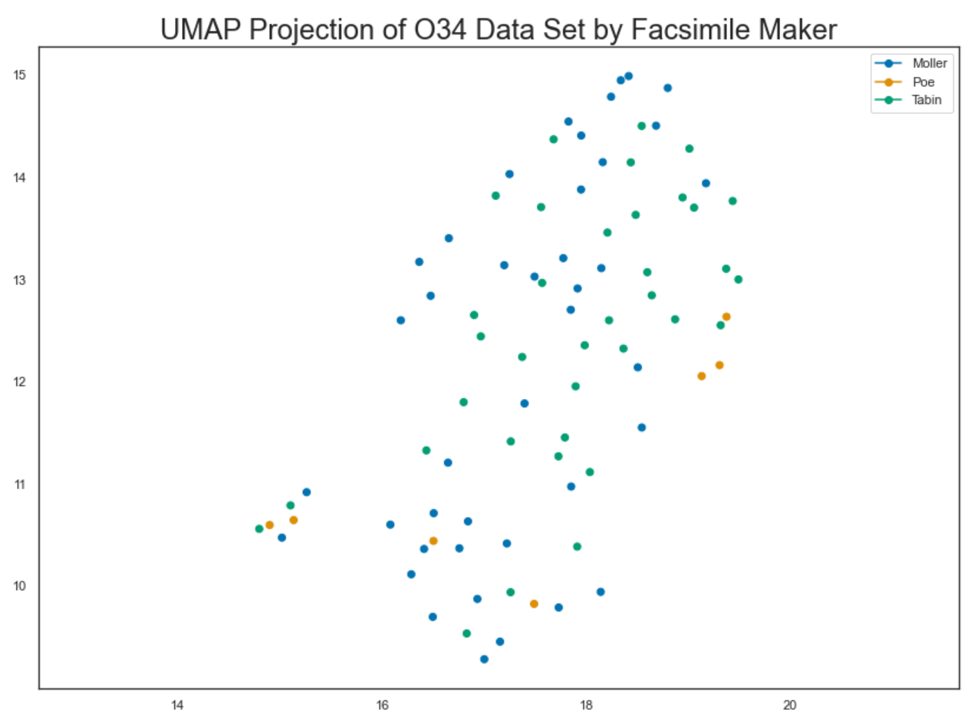

UMAP Projection of O29 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
−5.5
−6.0
−6.5
−7.0
−7.5
−8.0
−21
−20
−19
−18

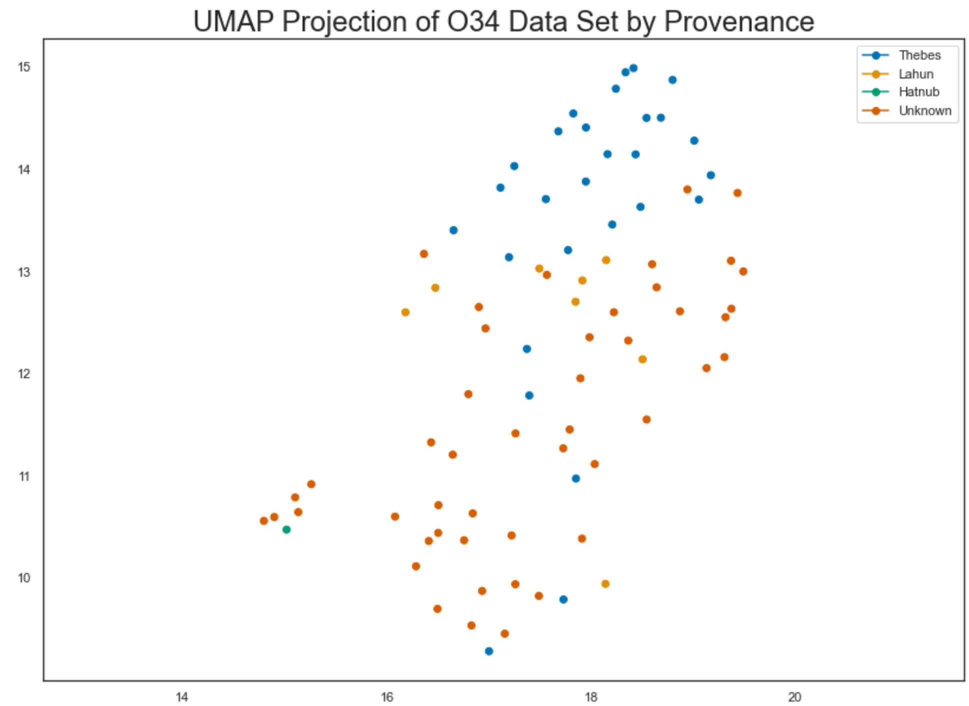

UMAP Projection of O29 Data Set by Facsimile Maker
Moller
Poe
Tabin
−5.5
−6.0
−6.5
−7.0
−7.5
−8.0
−21
−20
−19
−18

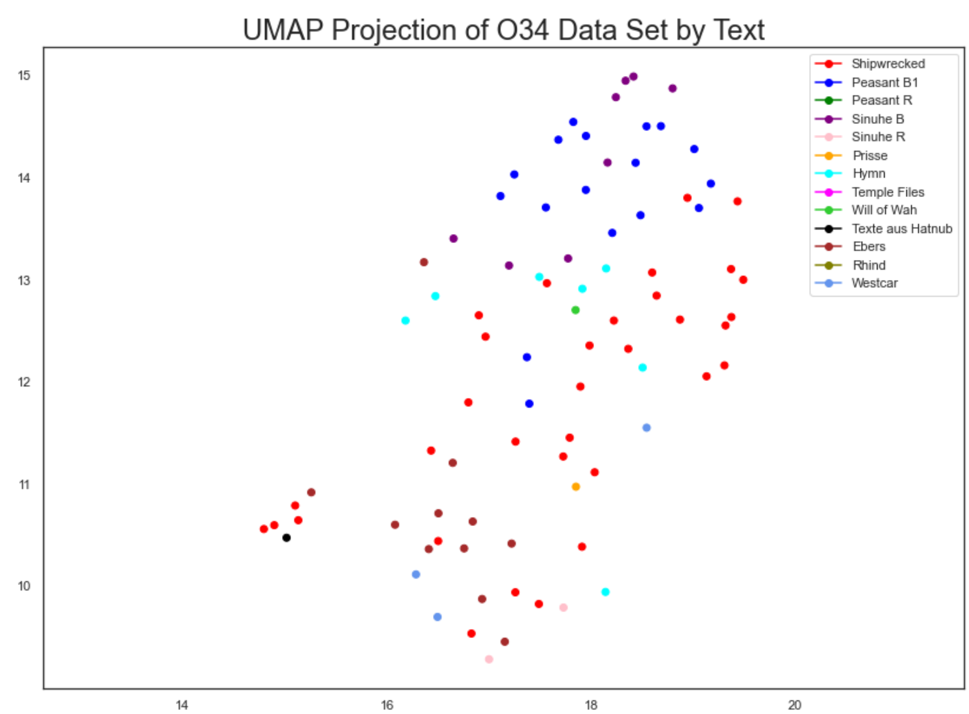

UMAP Projection of O29 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
-5.5
-6.0
-6.5
-7.0
-7.5
-8.0
-21
-20
-19
-18

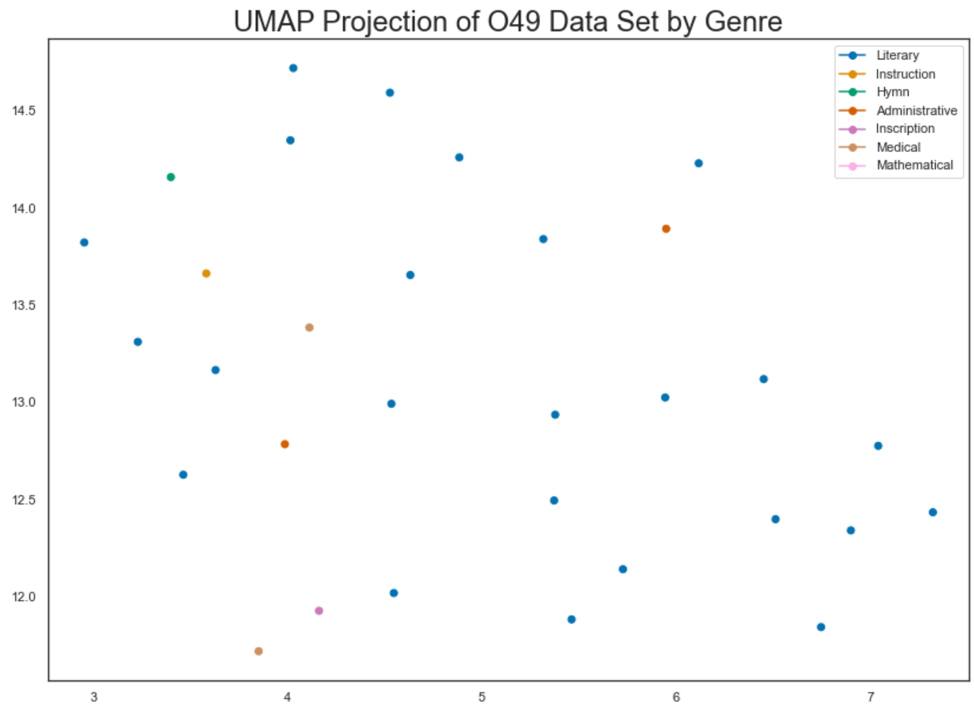

UMAP Projection of O29 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
-5.5
-6.0
-6.5
-7.0
-7.5
-8.0
-21
-20
-19
-18

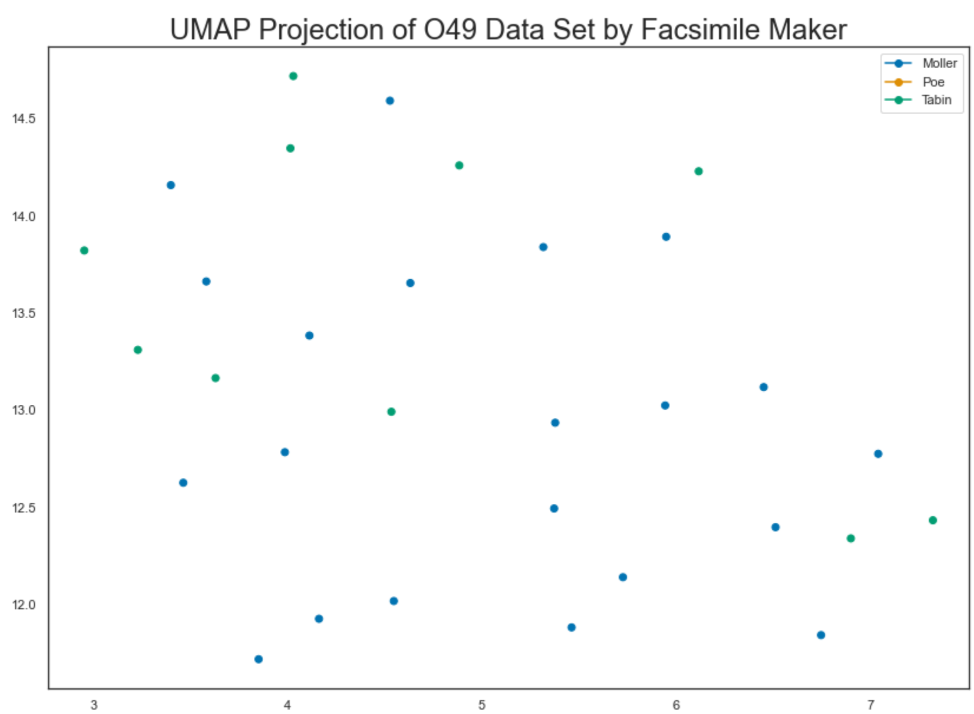

UMAP Projection of O34 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
15
14
13
12
11
10
14
16
18
20

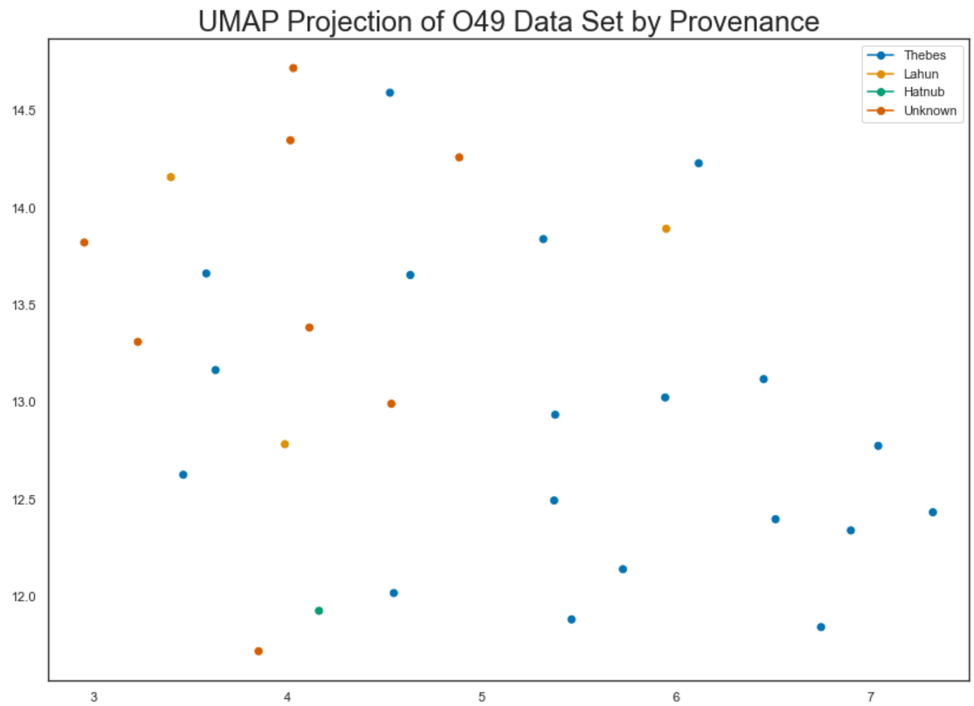

UMAP Projection of O34 Data Set by Facsimile Maker
Moller
Poe
Tabin
15
14
13
12
11
10
14
16
18
20

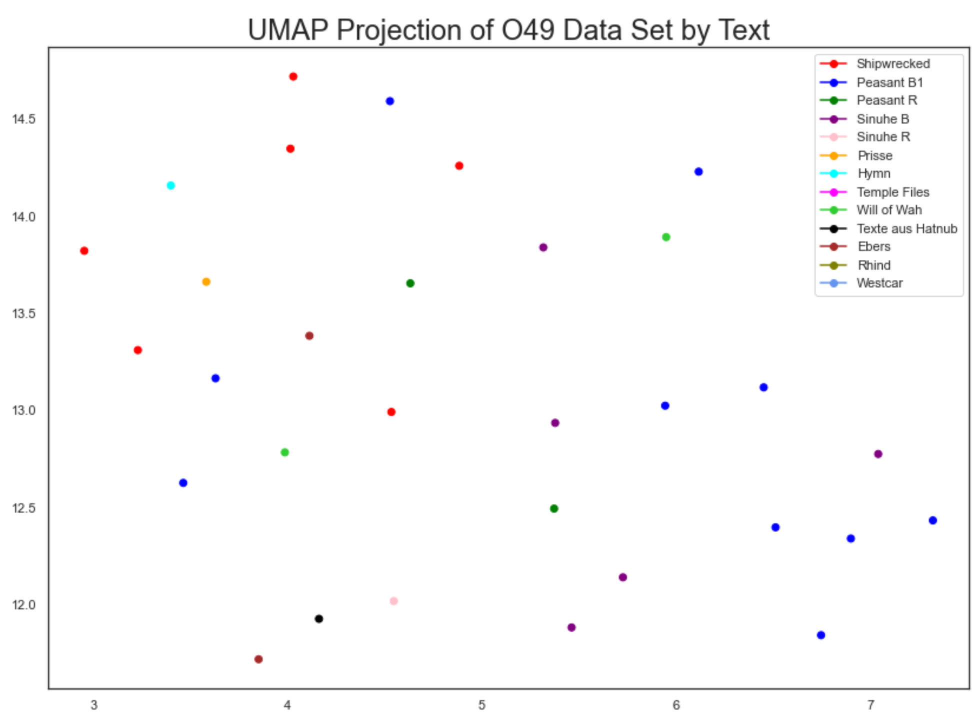

UMAP Projection of O34 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
15
14
13
12
11
10
14
16
18
20

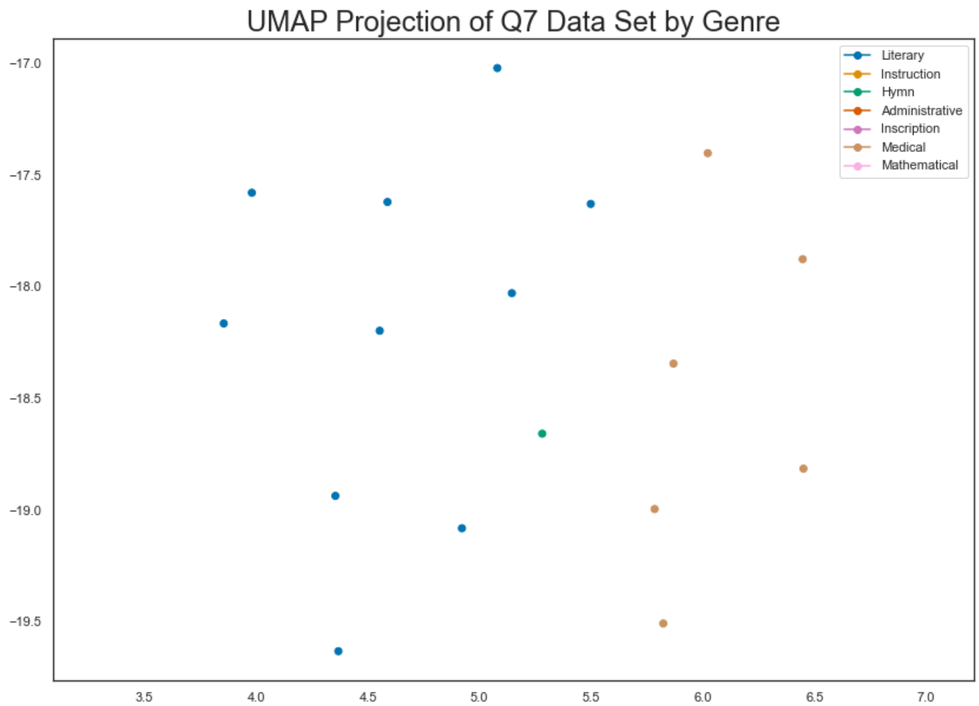

UMAP Projection of O34 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
15
14
13
12
11
10
14
16
18
20

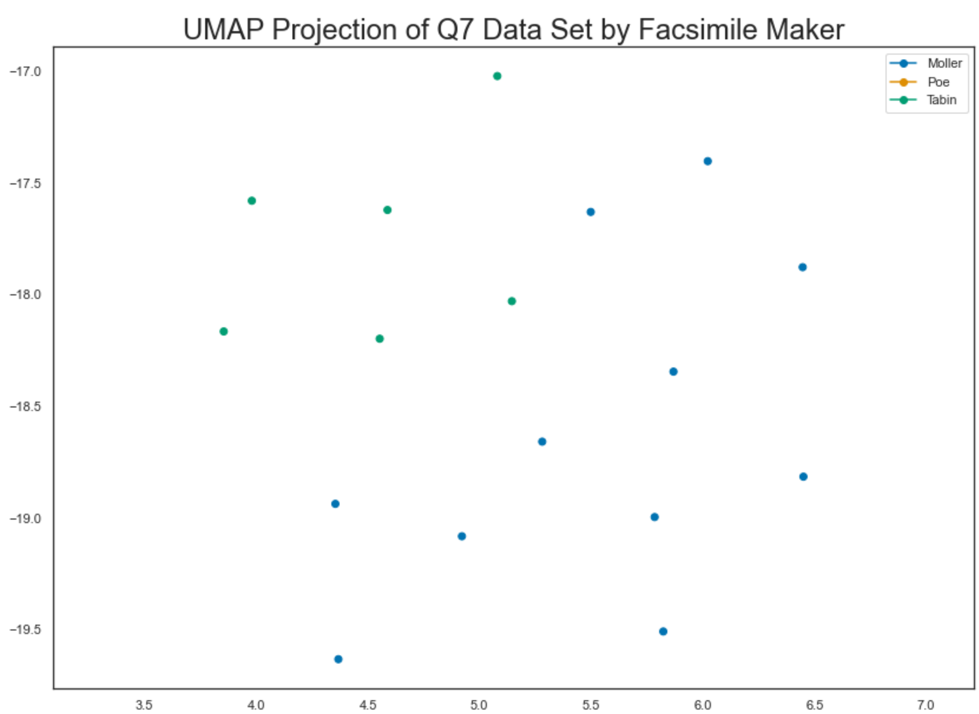

UMAP Projection of O49 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
14.5
14.0
13.5
13.0
12.5
12.0
3
4
5
6
7

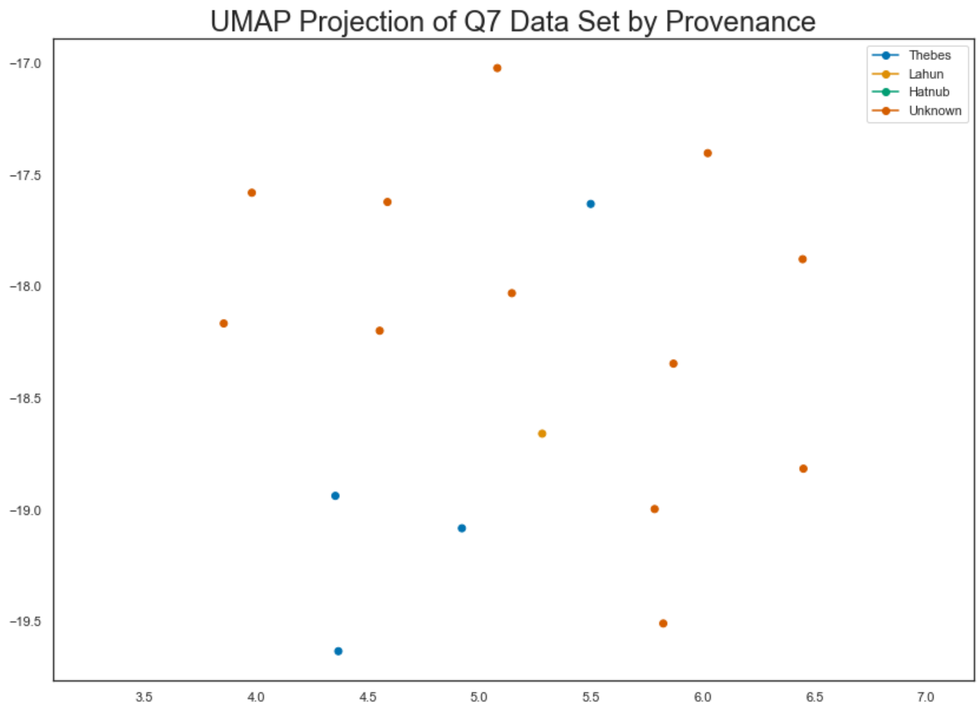

UMAP Projection of O49 Data Set by Facsimile Maker
Moller
Poe
Tabin
14.5
14.0
13.5
13.0
12.5
12.0
3
4
5
6
7

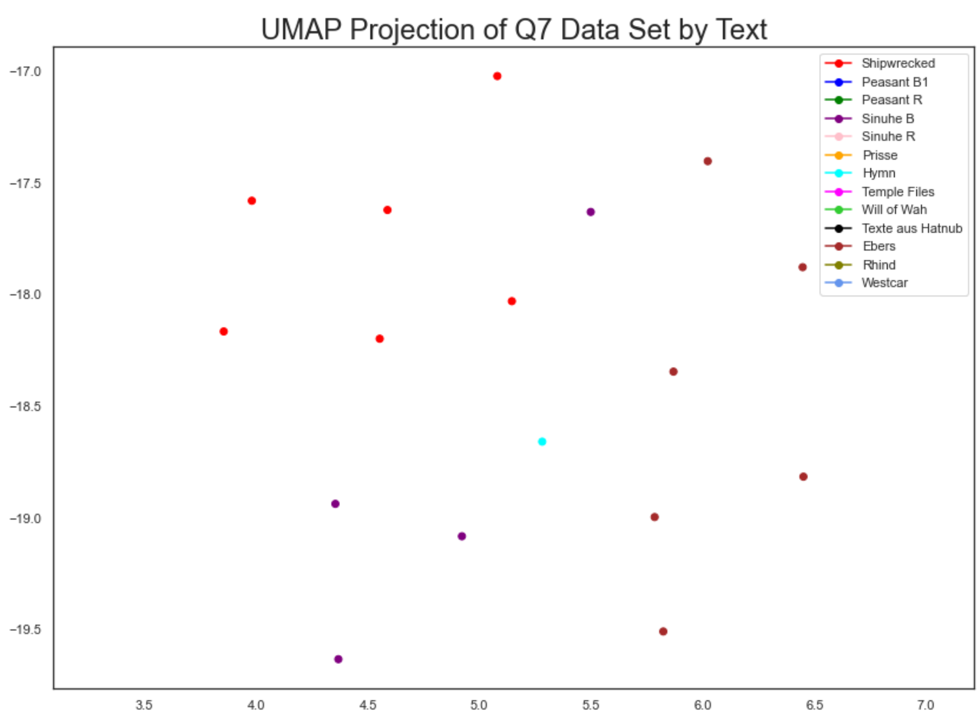

UMAP Projection of O49 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
14.5
14.0
13.5
13.0
12.5
12.0
3
4
5
6
7

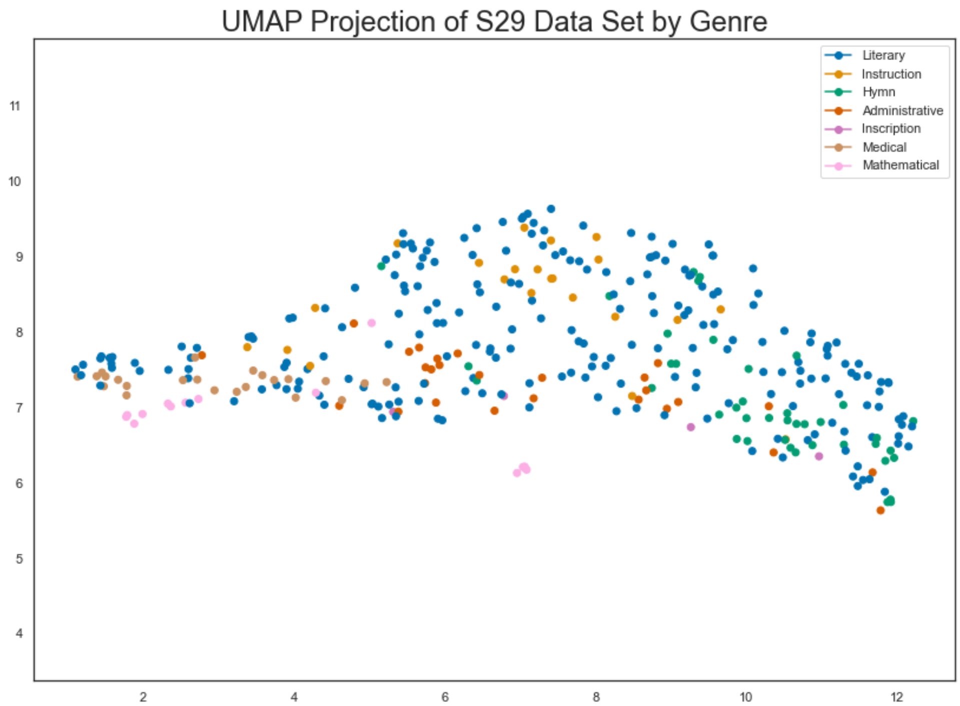

UMAP Projection of O49 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
14.5
14.0
13.5
13.0
12.5
12.0
3
4
5
6
7

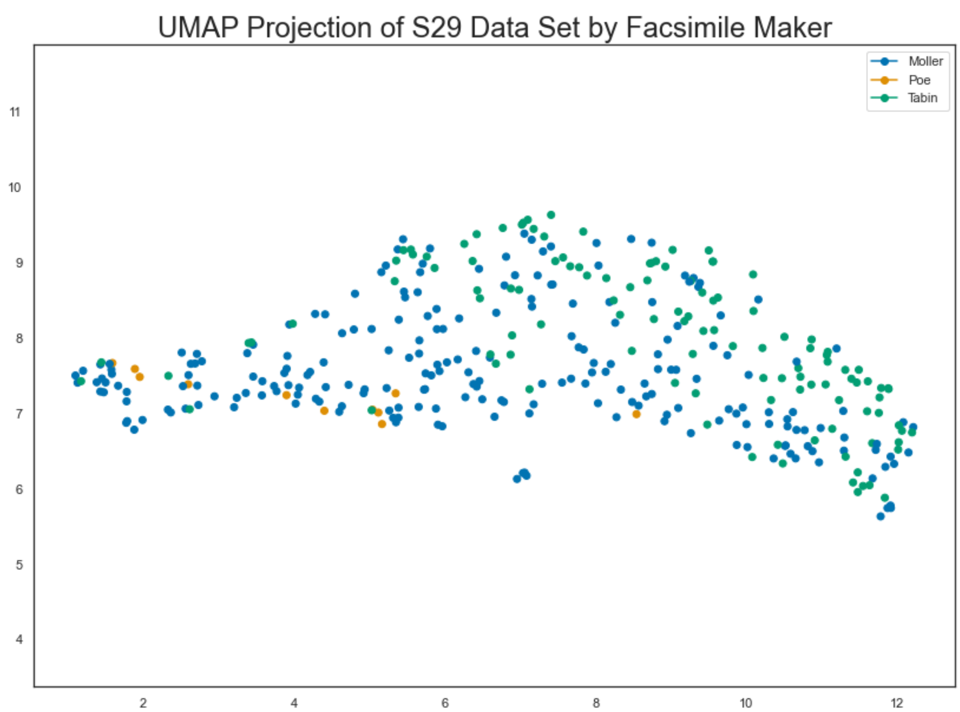

UMAP Projection of Q7 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
−17.0
−17.5
−18.0
−18.5
−19.0
−19.5
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

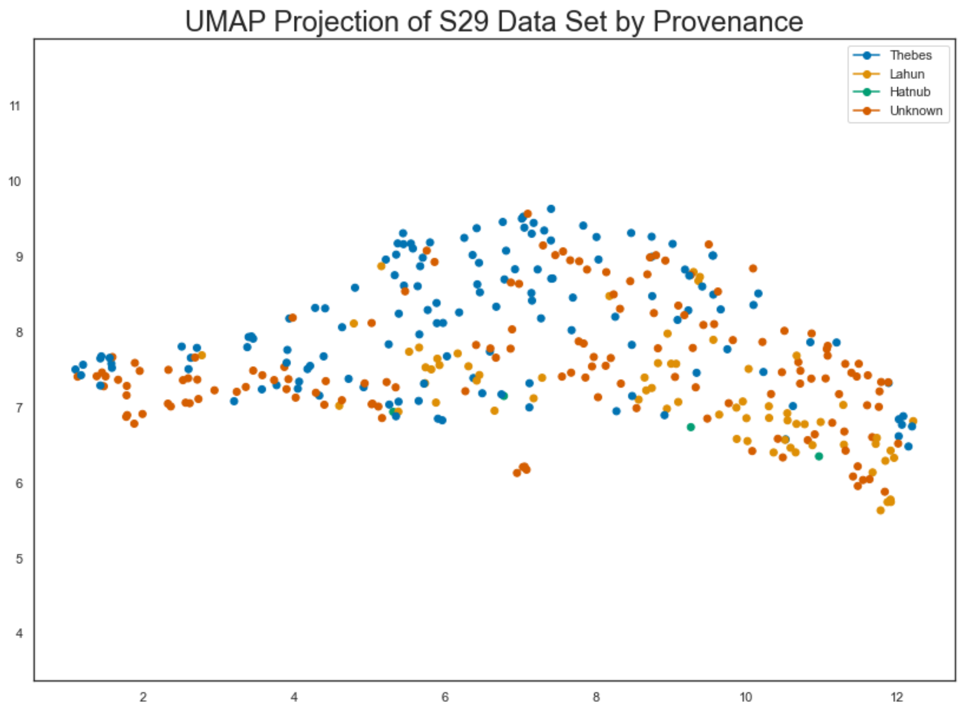

UMAP Projection of Q7 Data Set by Facsimile Maker
Moller
Poe
Tabin
−17.0
−17.5
−18.0
−18.5
−19.0
−19.5
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

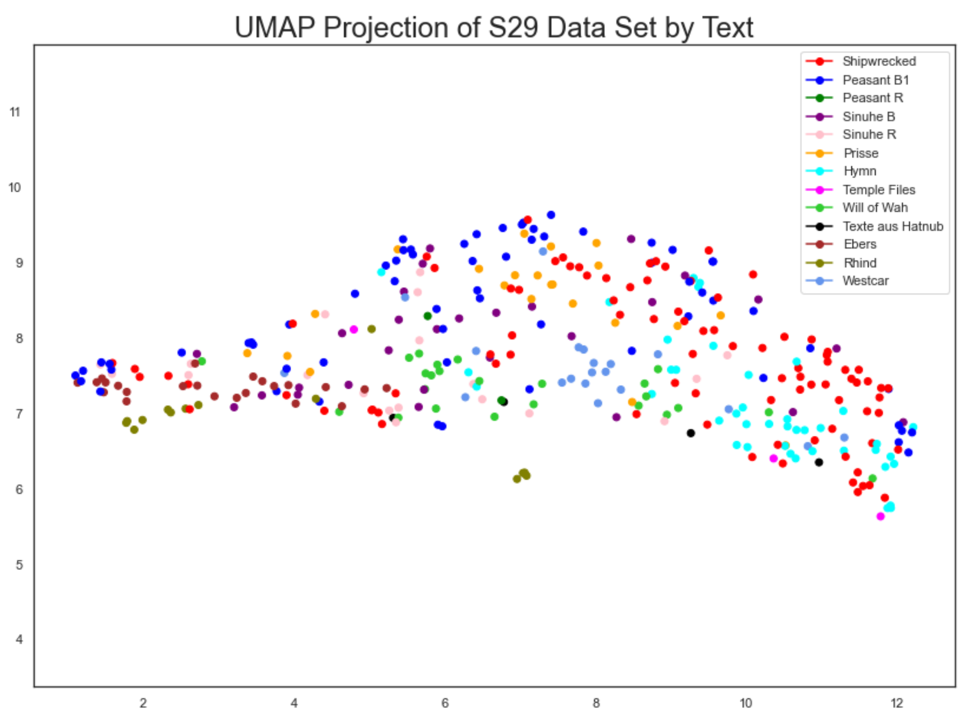

UMAP Projection of Q7 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
−17.0
−17.5
−18.0
−18.5
−19.0
−19.5
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

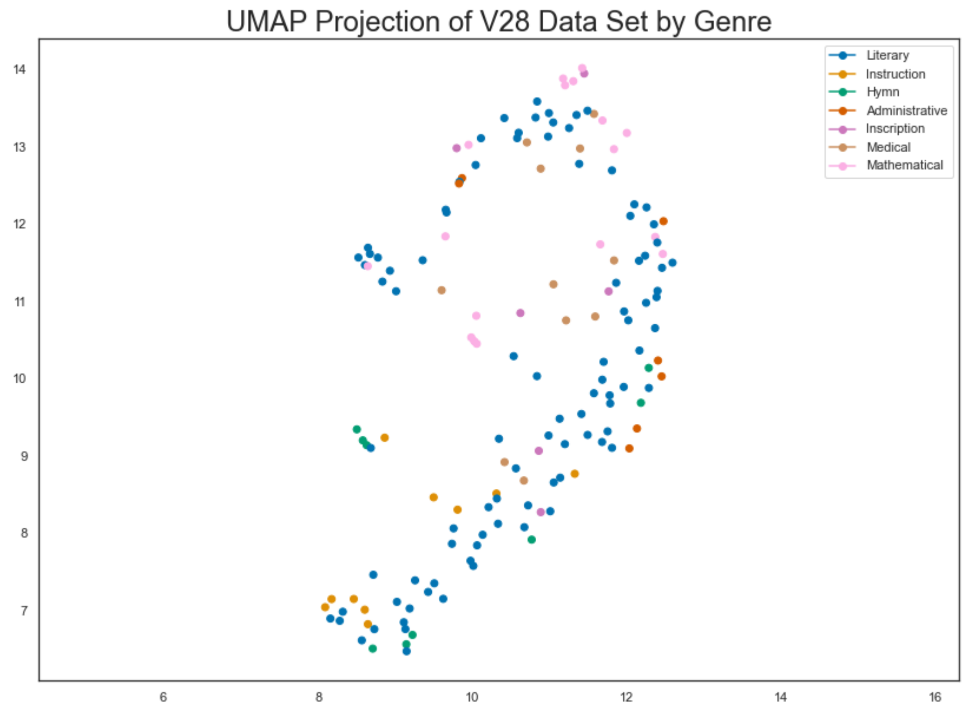

UMAP Projection of Q7 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
−17.0
−17.5
−18.0
−18.5
−19.0
−19.5
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

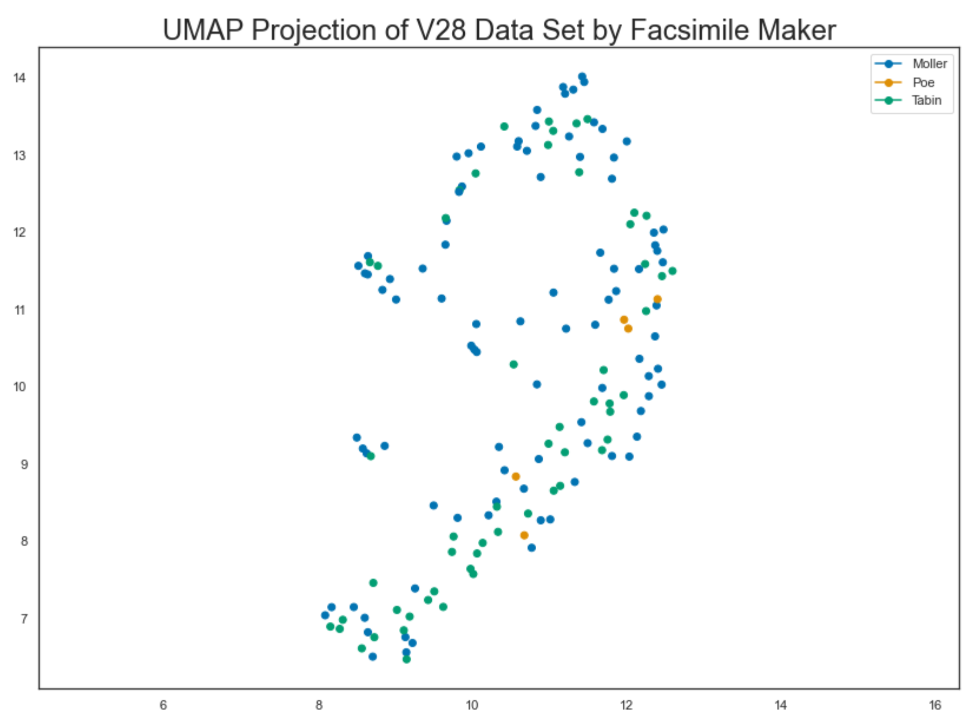

UMAP Projection of S29 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
11
10
9
8
7
6
5
4
2
4
6
8
10
12


UMAP Projection of S29 Data Set by Facsimile Maker
Moller
Poe
Tabin
11
10
9
8
7
6
5
4
2
4
6
8
10
12

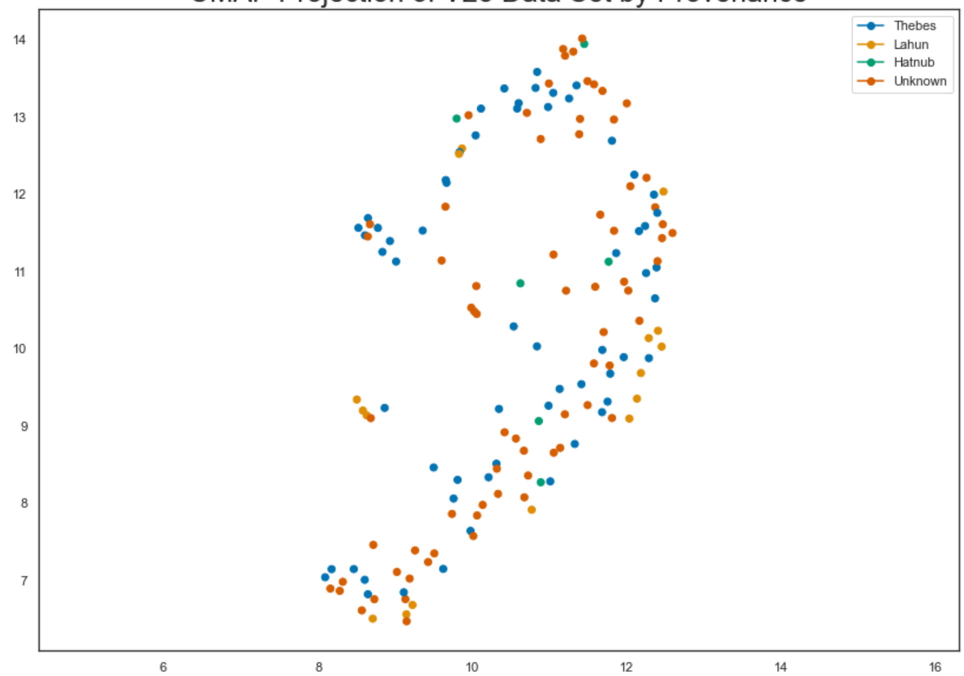

UMAP Projection of S29 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
11
10
9
8
7
6
5
4
2
4
6
8
10
12


UMAP Projection of S29 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
11
10
9
8
7
6
5
4
2
4
6
8
10
12

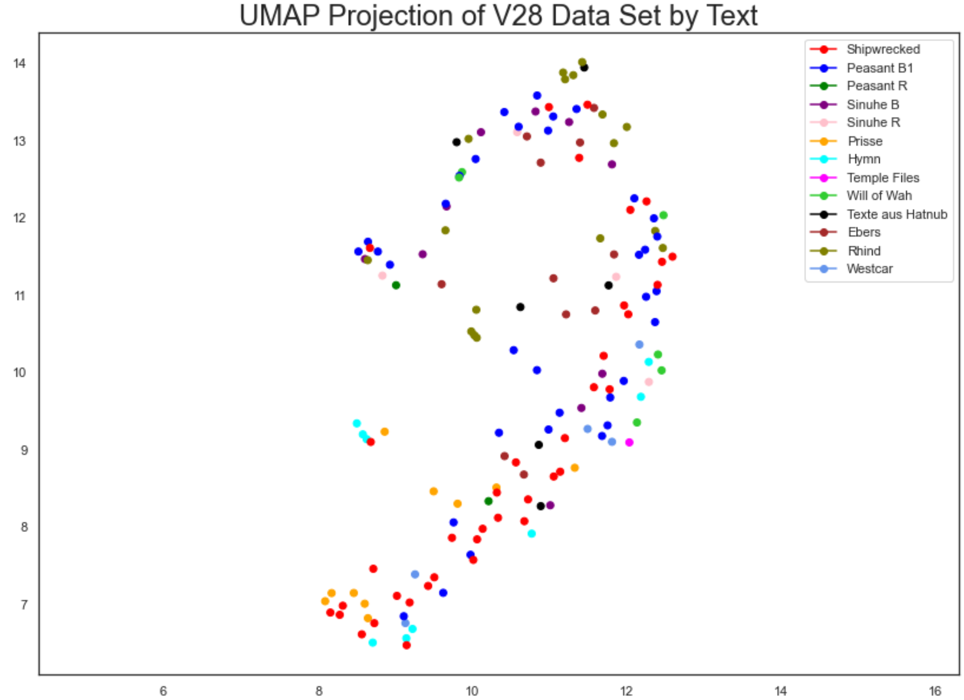

UMAP Projection of V28 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
14
13
12
11
10
9
8
7
6
8
10
12
14
16


UMAP Projection of V28 Data Set by Facsimile Maker
Moller
Poe
Tabin
14
13
12
11
10
9
8
7
6
8
10
12
14
16

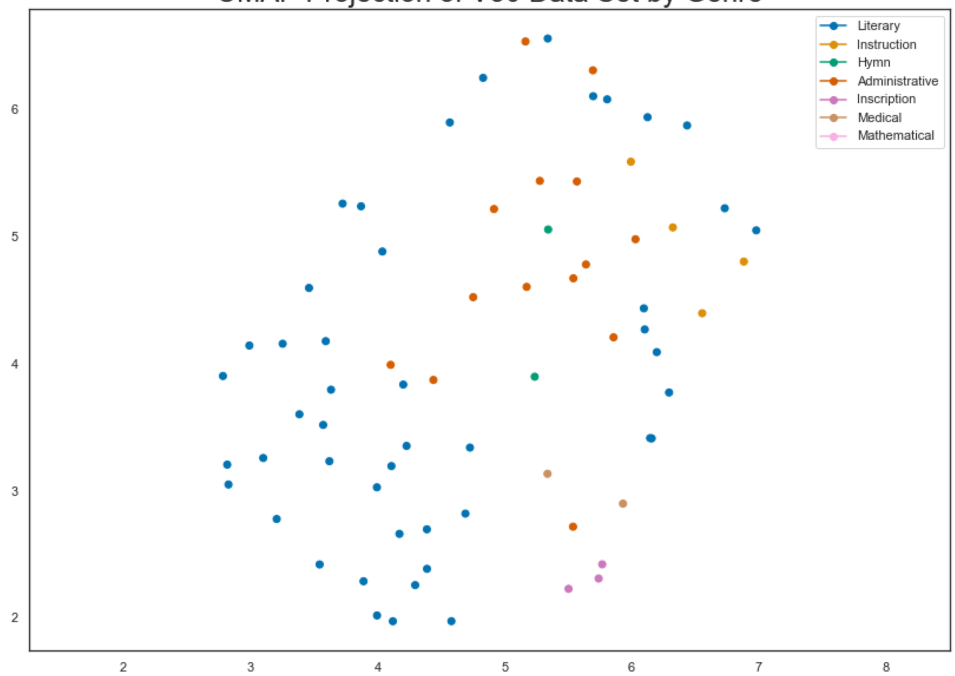
UMAP Projection of V28 Data Set by Provenance



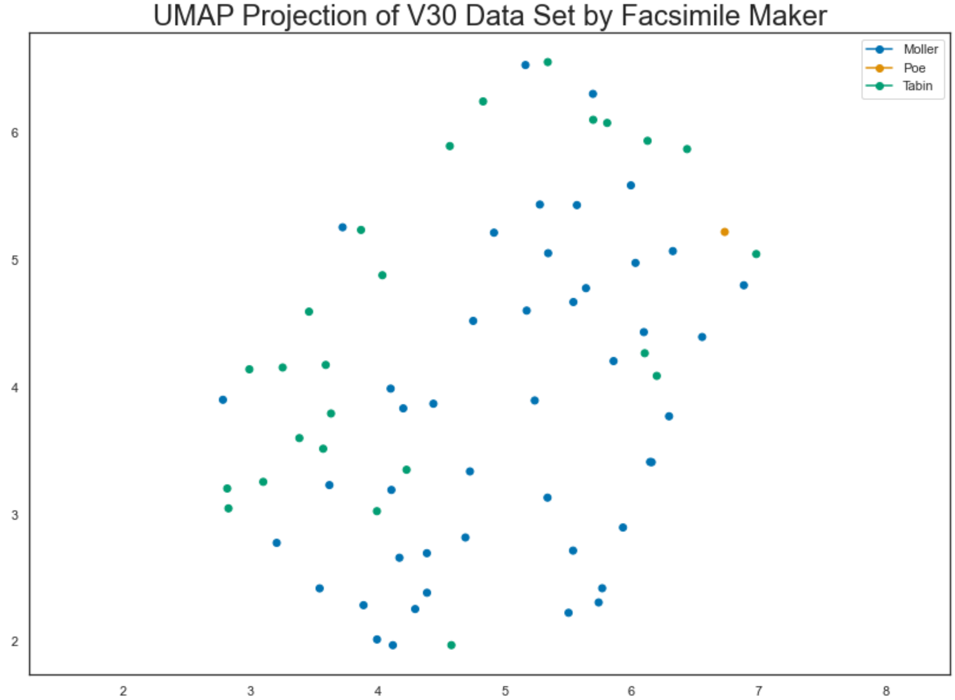
UMAP Projection of V28 Data Set by Text

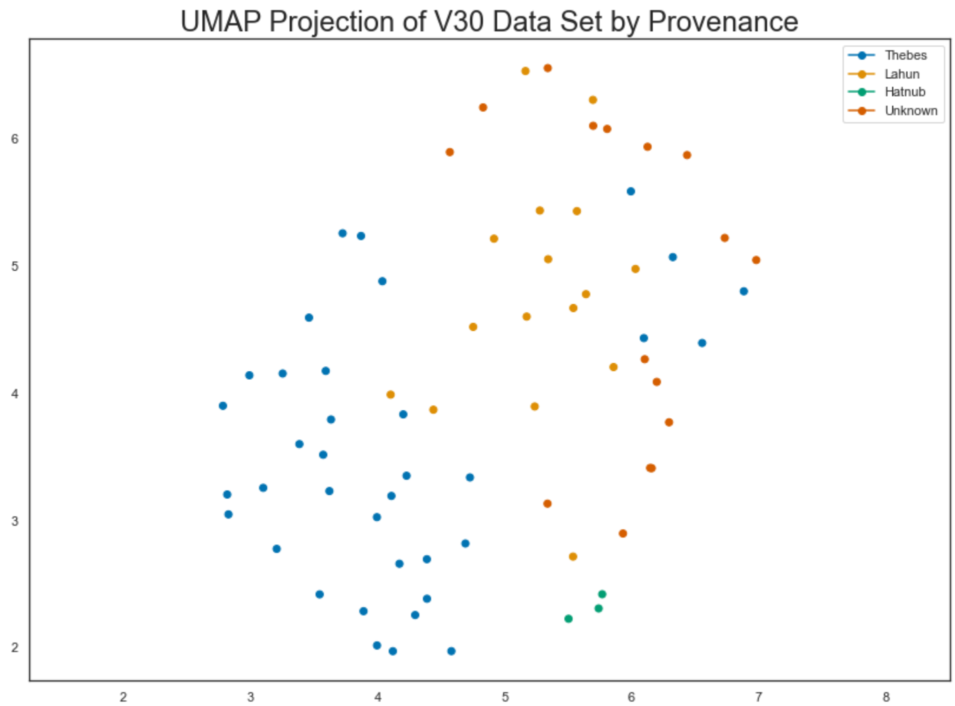


UMAP Projection of V30 Data Set by Genre

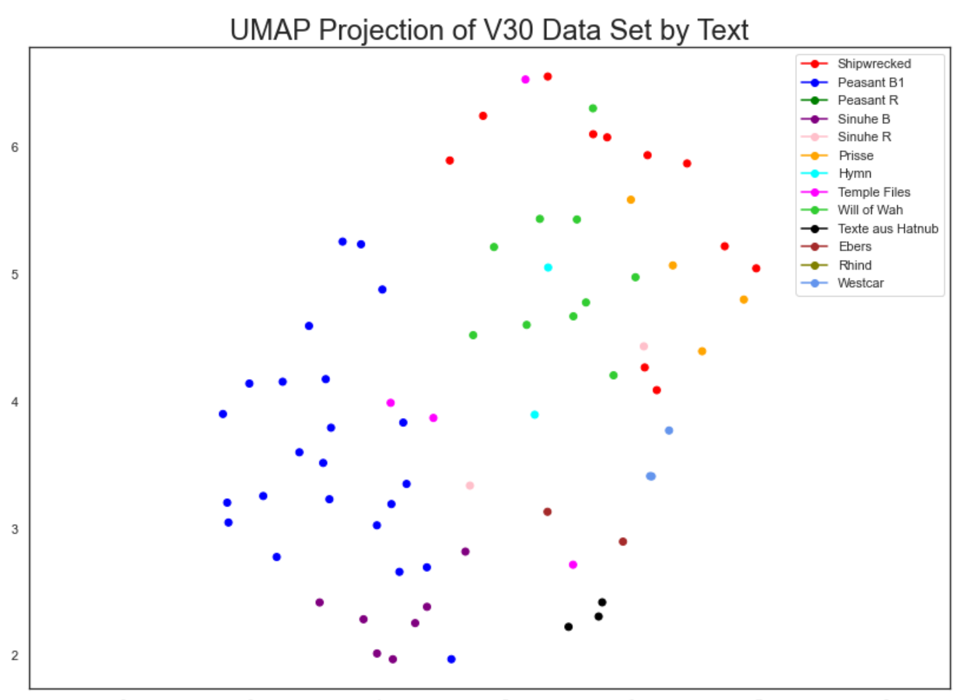


UMAP Projection of V30 Data Set by Facsimile Maker

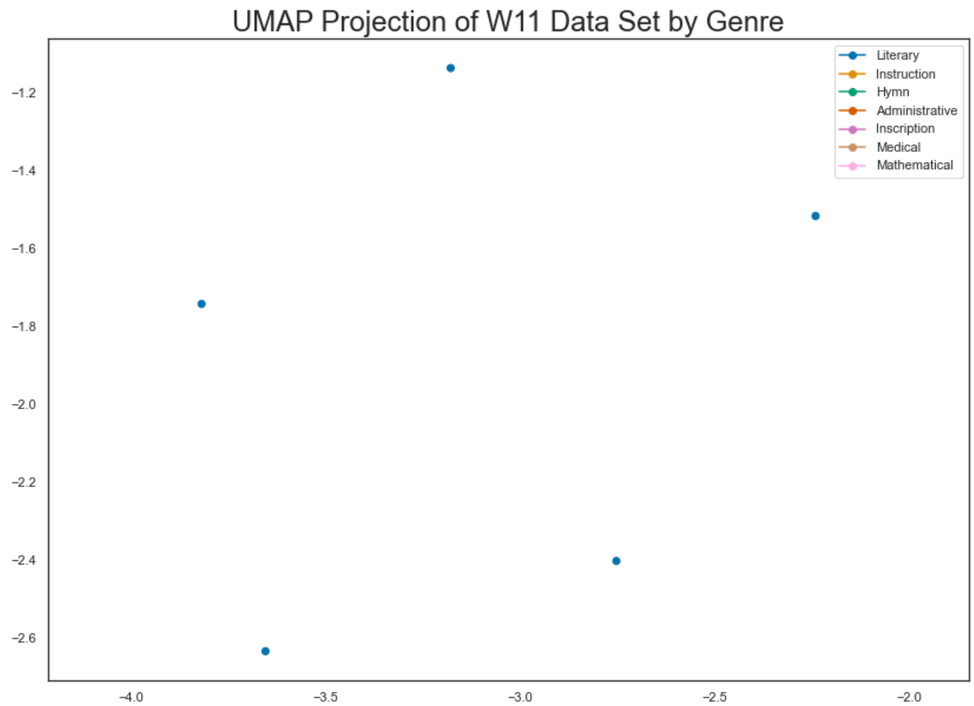


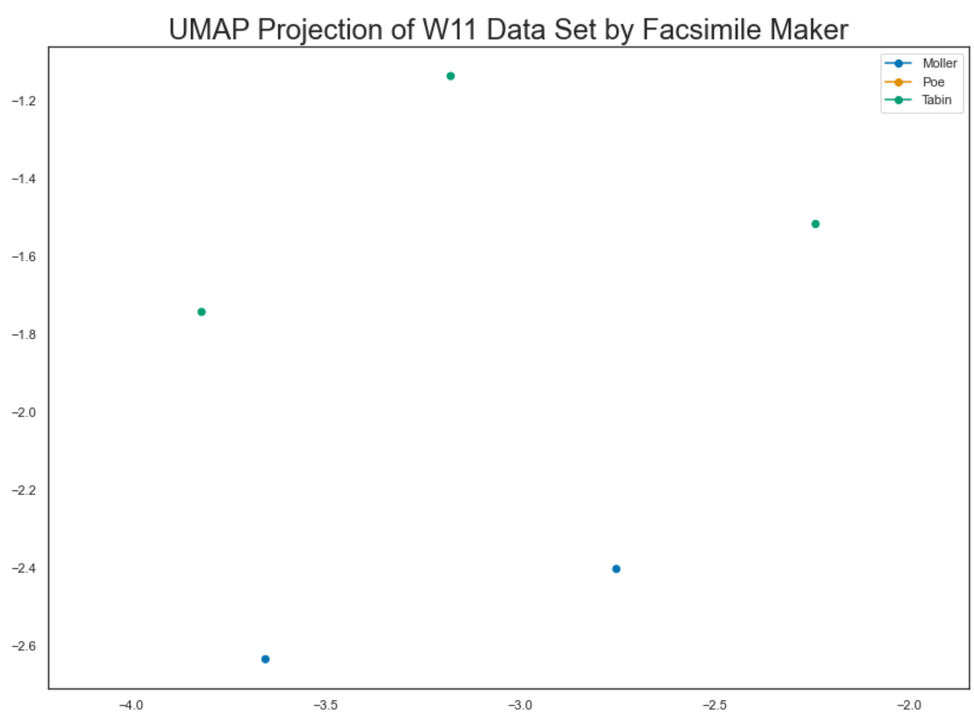


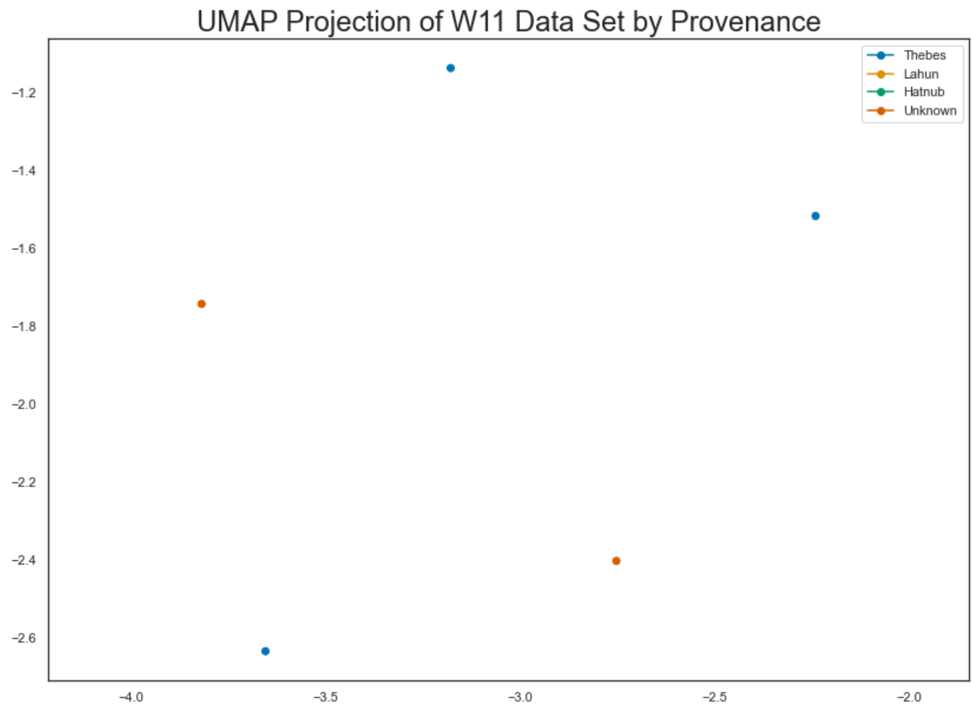
UMAP Projection of V30 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
2
3
4
5
6
7
8

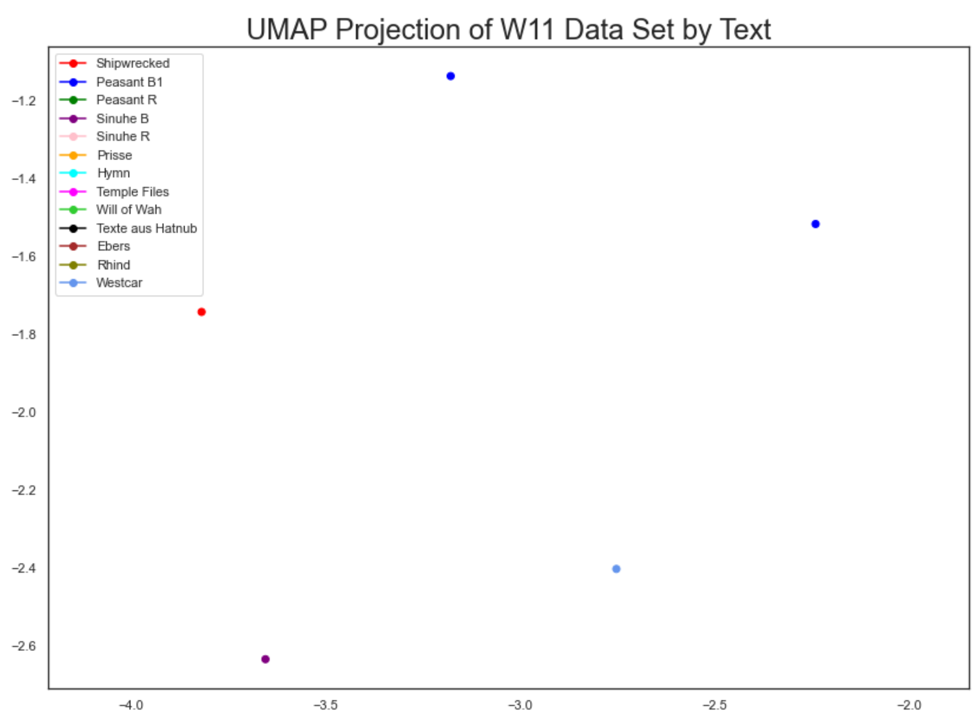


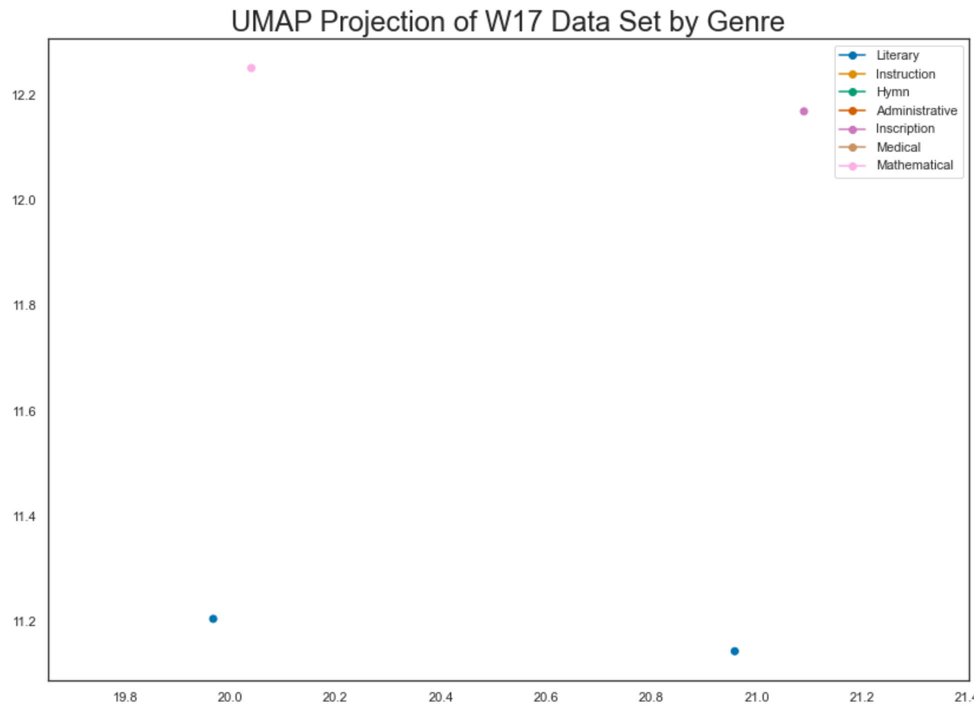
UMAP Projection of V30 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
2
3
4
5
6
7
8

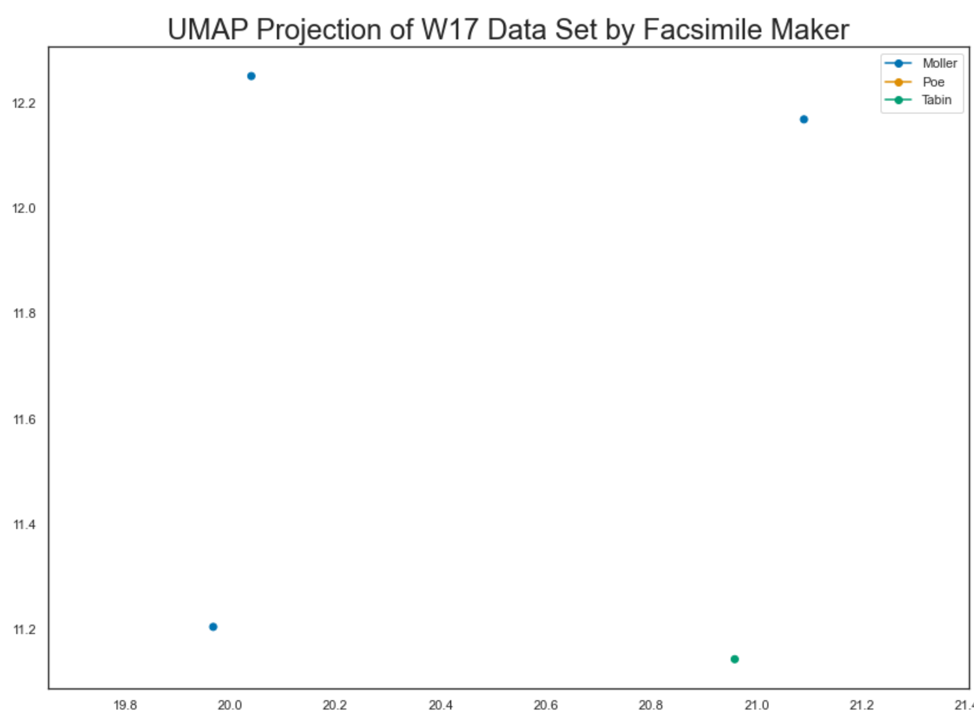

UMAP Projection of W11 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
−1.2
−1.4
−1.6
−1.8
−2.0
−2.2
−2.4
−2.6
−4.0
−3.5
−3.0
−2.5
−2.0

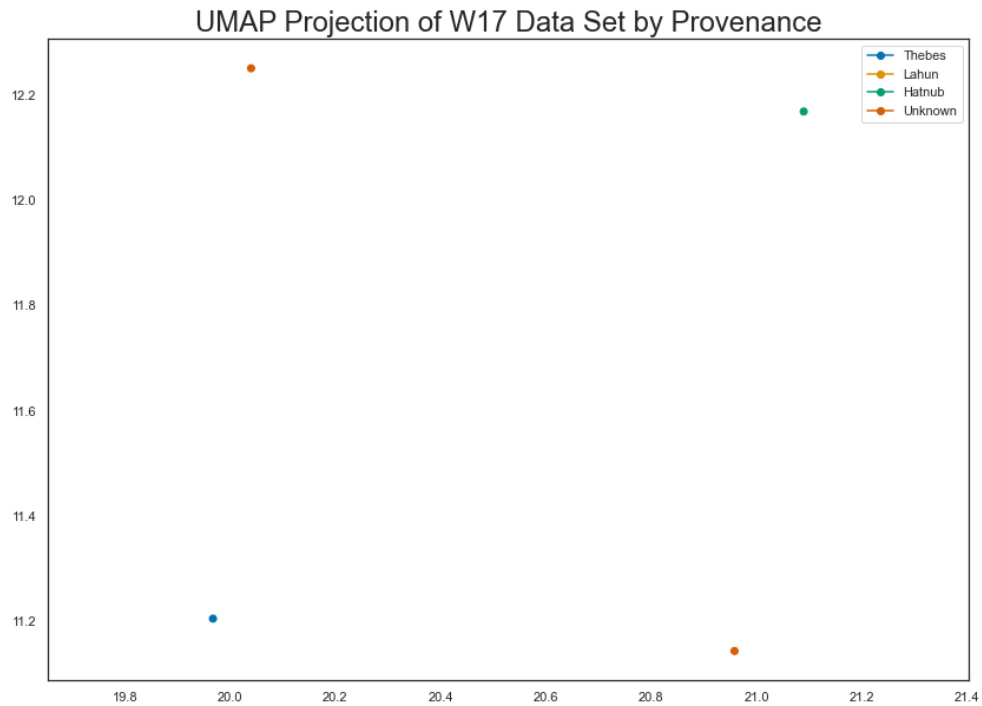

UMAP Projection of W11 Data Set by Facsimile Maker
Moller
Poe
Tabin
−1.2
−1.4
−1.6
−1.8
−2.0
−2.2
−2.4
−2.6
−4.0
−3.5
−3.0
−2.5
−2.0

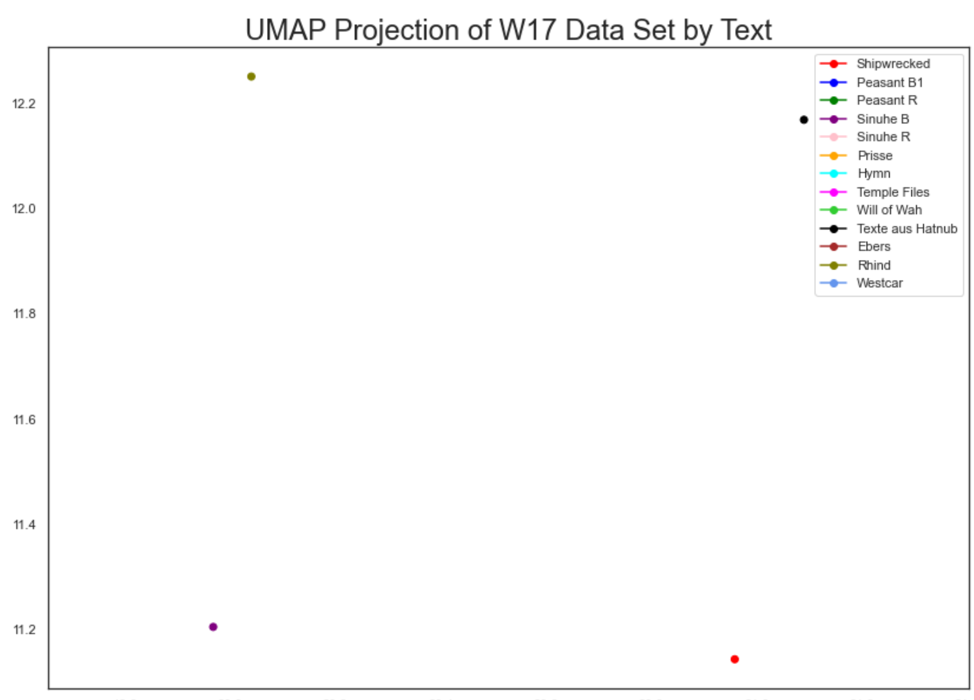

UMAP Projection of W11 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
−1.2
−1.4
−1.6
−1.8
−2.0
−2.2
−2.4
−2.6
−4.0
−3.5
−3.0
−2.5
−2.0

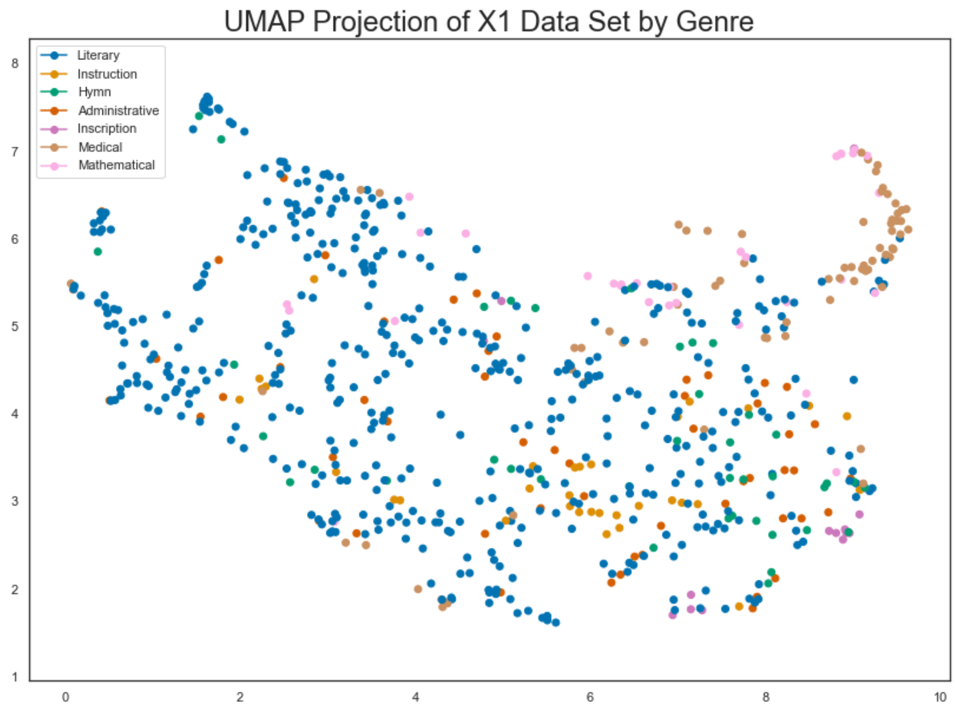

UMAP Projection of W11 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
−1.2
−1.4
−1.6
−1.8
−2.0
−2.2
−2.4
−2.6
−4.0
−3.5
−3.0
−2.5
−2.0

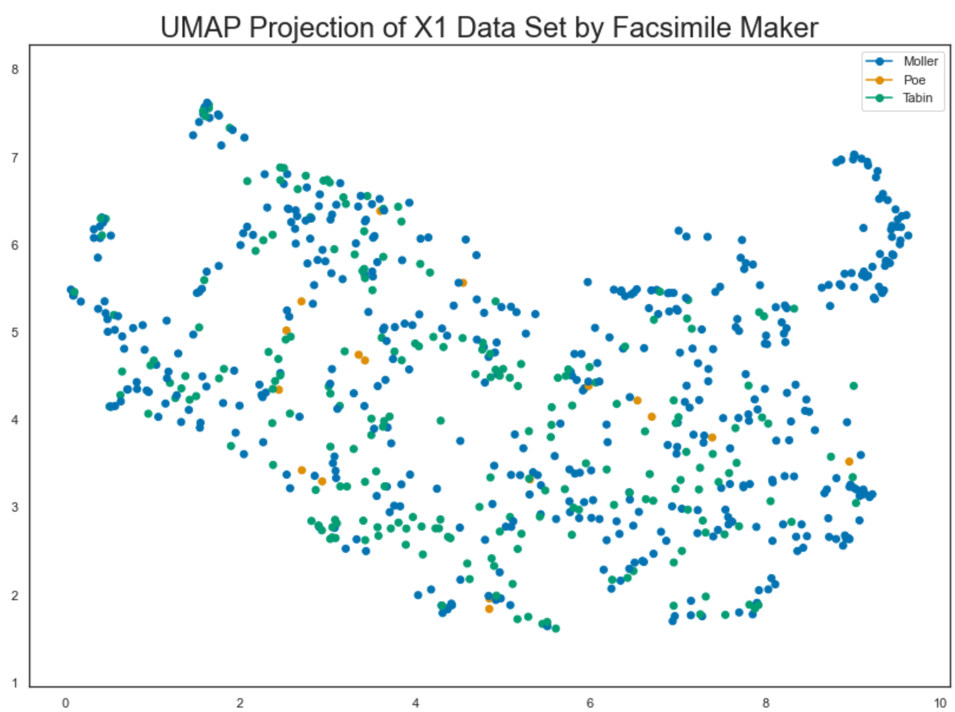

UMAP Projection of W17 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
12.2
12.0
11.8
11.6
11.4
11.2
19.8
20.0
20.2
20.4
20.6
20.8
21.0
21.2
21.4

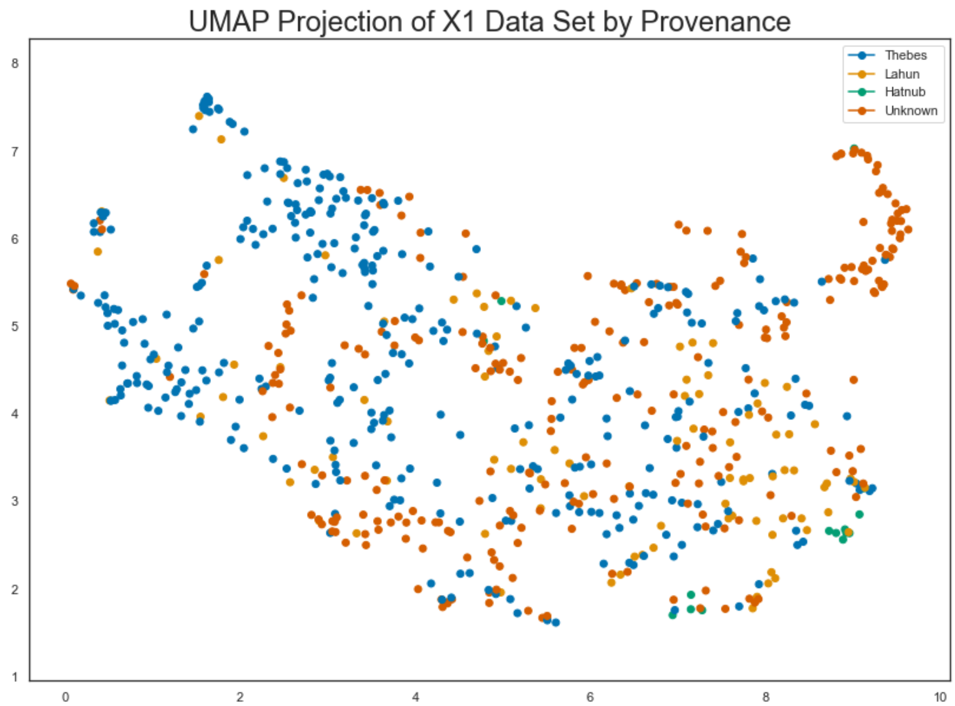

UMAP Projection of W17 Data Set by Facsimile Maker
Moller
Poe
Tabin
12.2
12.0
11.8
11.6
11.4
11.2
19.8
20.0
20.2
20.4
20.6
20.8
21.0
21.2
21.4

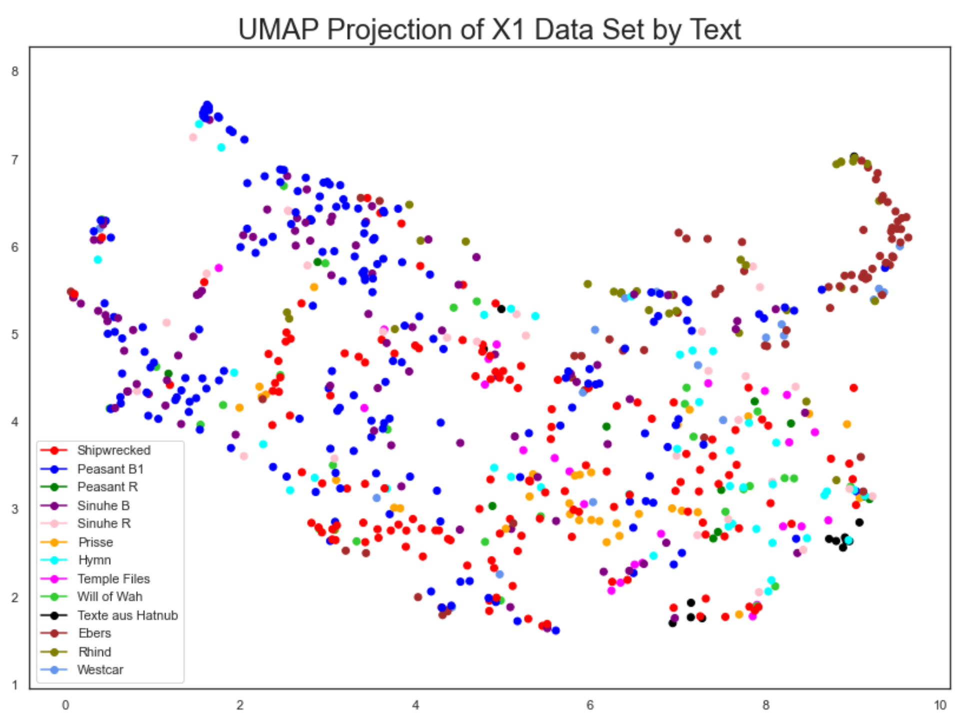

UMAP Projection of W17 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
12.2
12.0
11.8
11.6
11.4
11.2
19.8
20.0
20.2
20.4
20.6
20.8
21.0
21.2
21.4

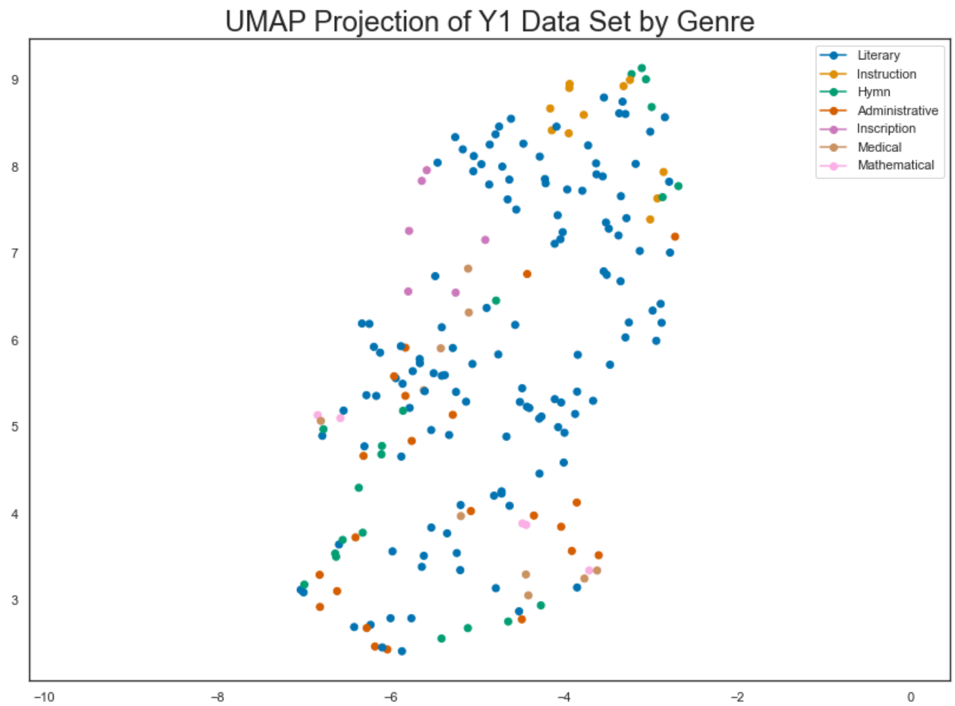

UMAP Projection of W17 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
12.2
12.0
11.8
11.6
11.4
11.2
19.8
20.0
20.2
20.4
20.6
20.8
21.0
21.2
21.4

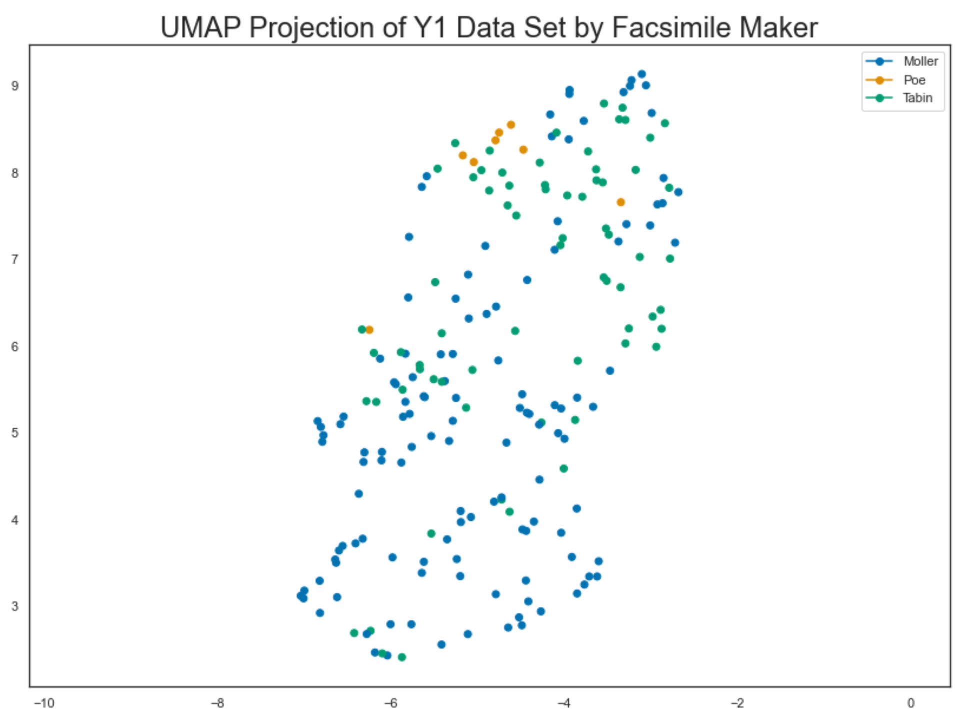

UMAP Projection of X1 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
8
7
6
5
4
3
2
1
0
2
4
6
8
10

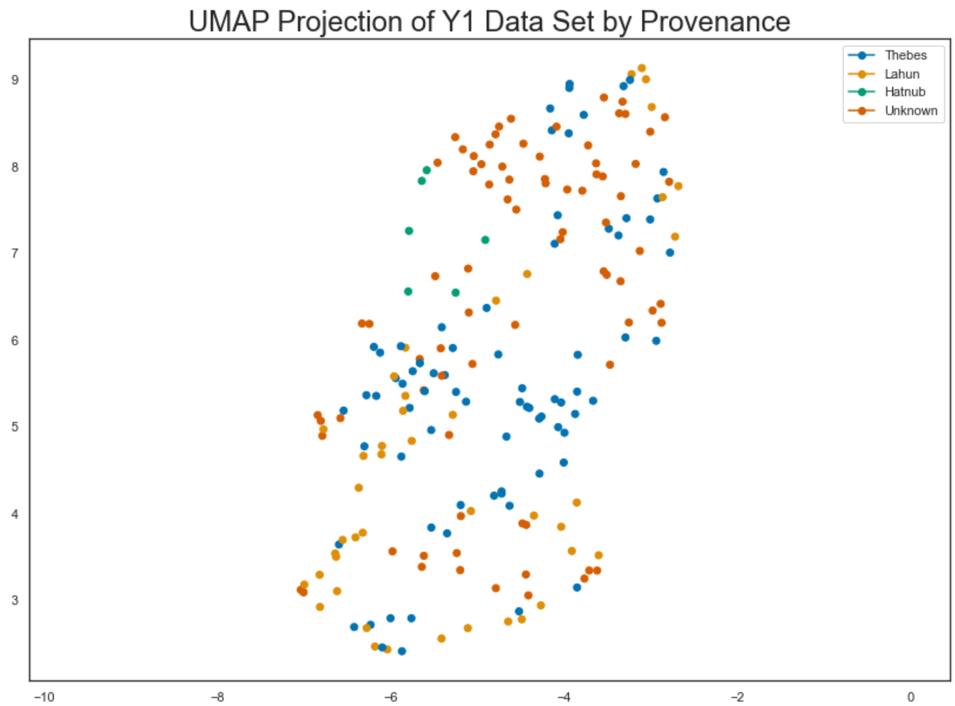

UMAP Projection of X1 Data Set by Facsimile Maker
Moller
Poe
Tabin
8
7
6
5
4
3
2
1
0
2
4
6
8
10

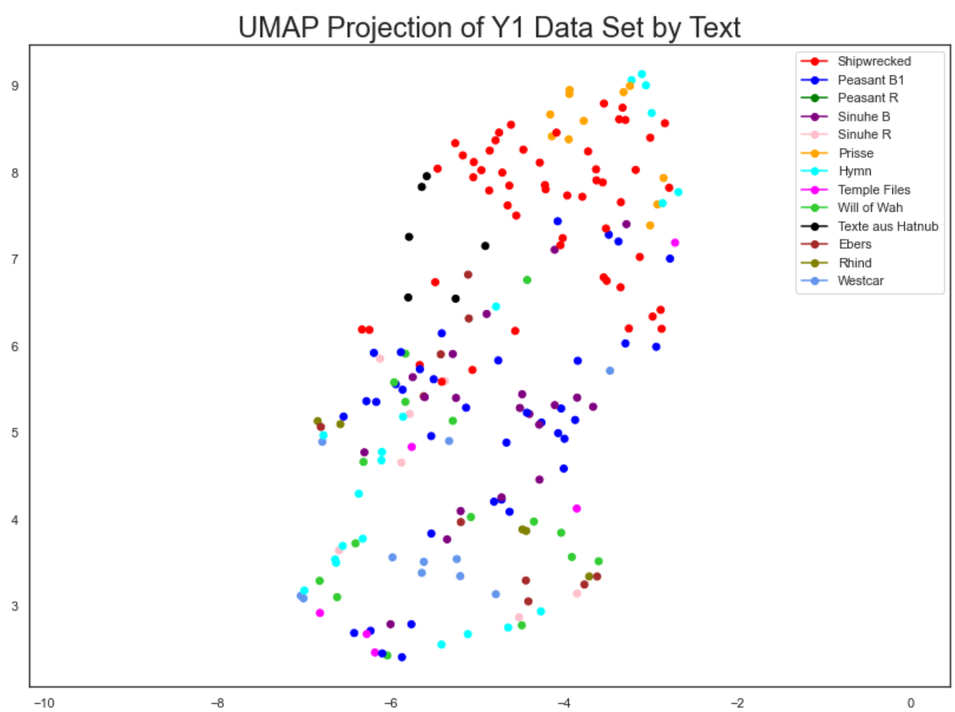

UMAP Projection of X1 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
8
7
6
5
4
3
2
1
0
2
4
6
8
10

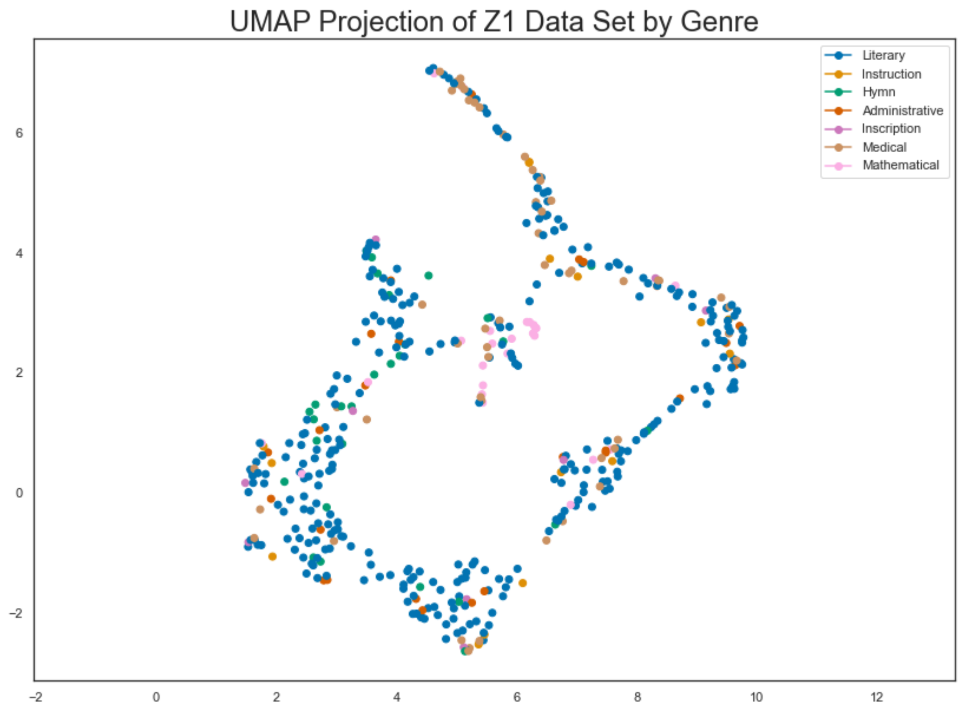

UMAP Projection of X1 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
8
7
6
5
4
3
2
1
0
2
4
6
8
10

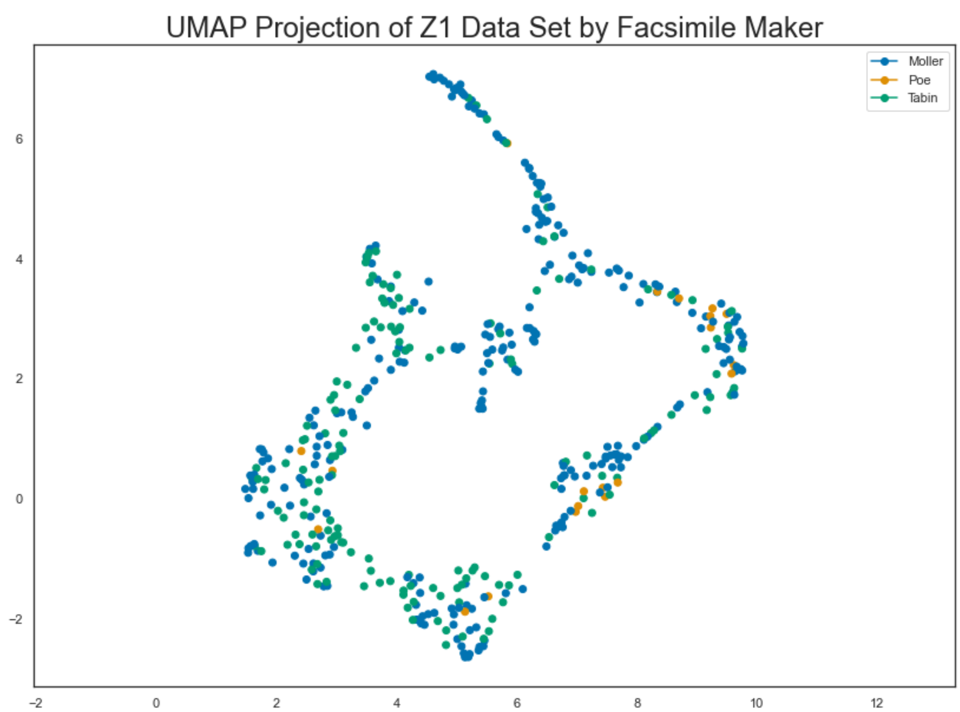

UMAP Projection of Y1 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
9
8
7
6
5
4
3
−10
−8
−6
−4
−2
0

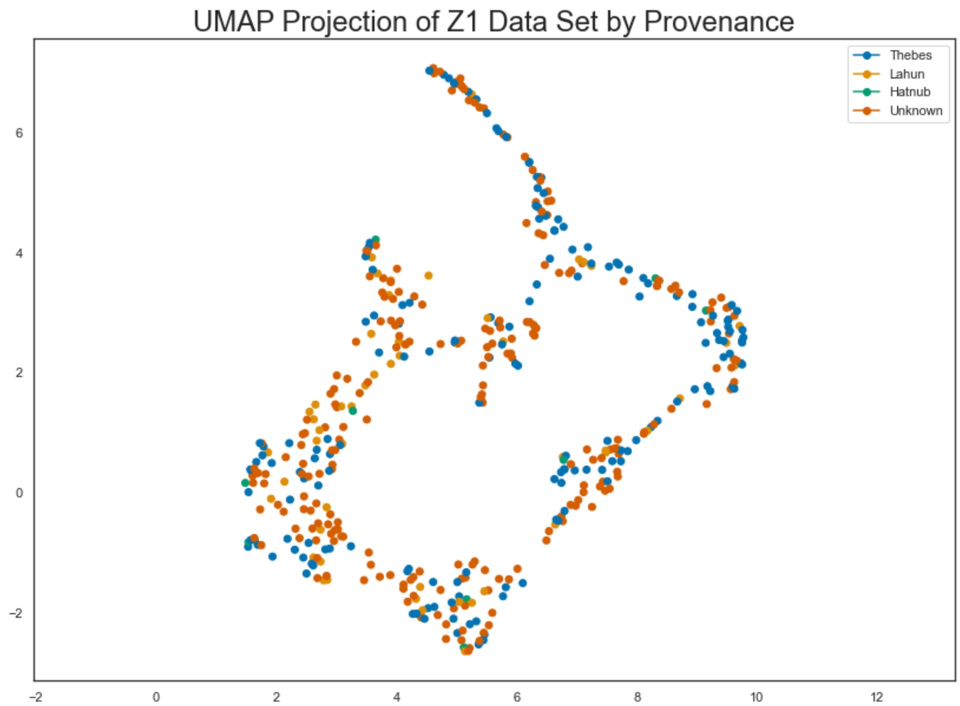

UMAP Projection of Y1 Data Set by Facsimile Maker
Moller
Poe
Tabin
9
8
7
6
5
4
3
−10
−8
−6
−4
−2
0

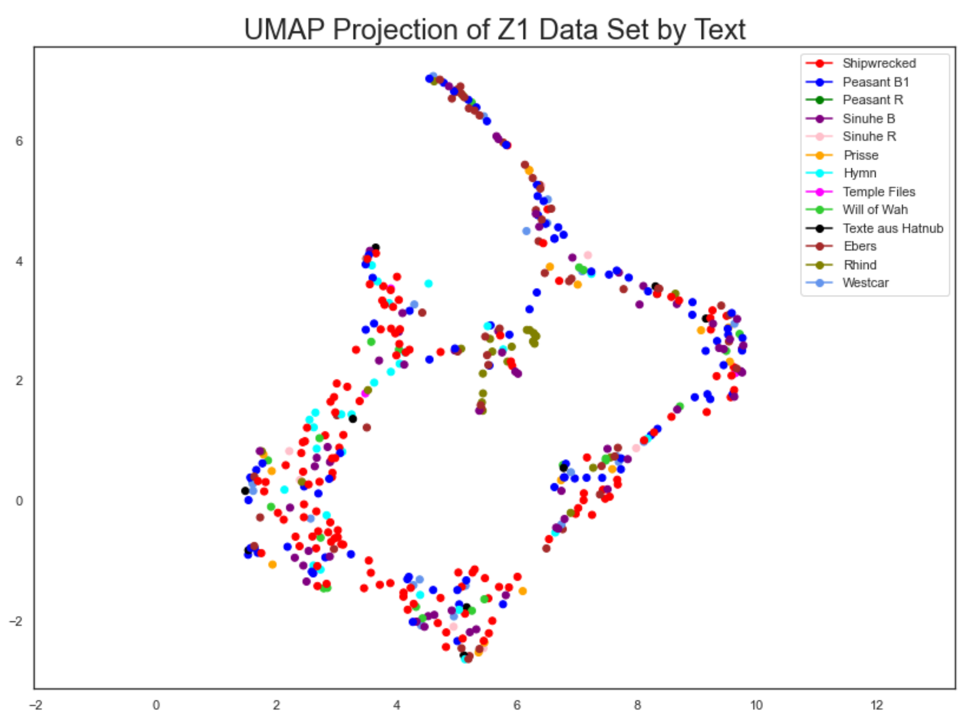

UMAP Projection of Y1 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
9
8
7
6
5
4
3
−10
−8
−6
−4
−2
0

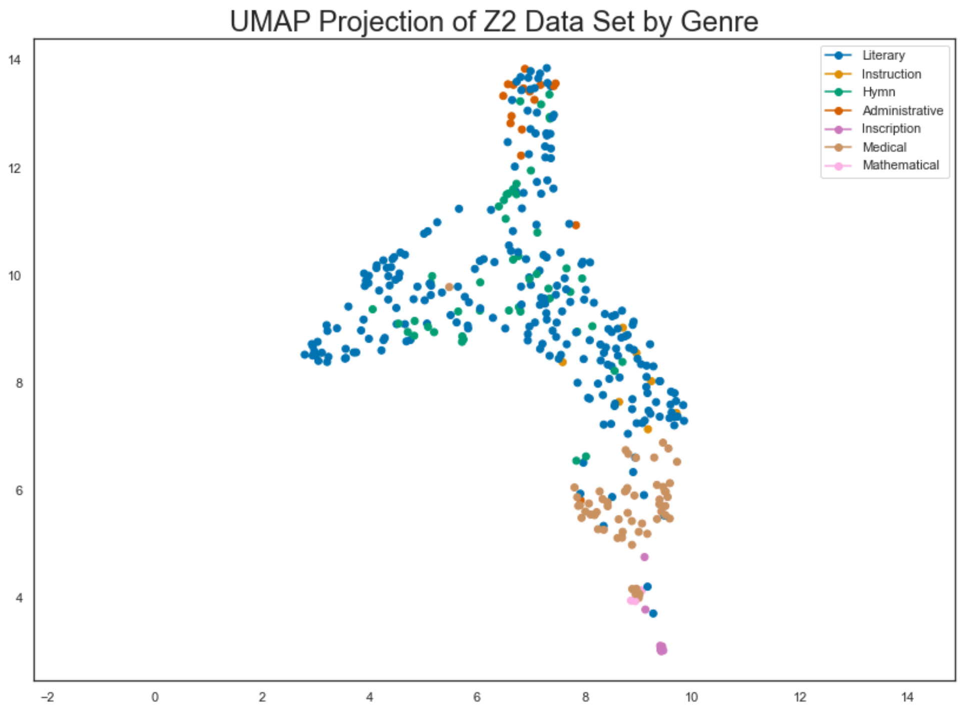

UMAP Projection of Y1 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
9
8
7
6
5
4
3
−10
−8
−6
−4
−2
0

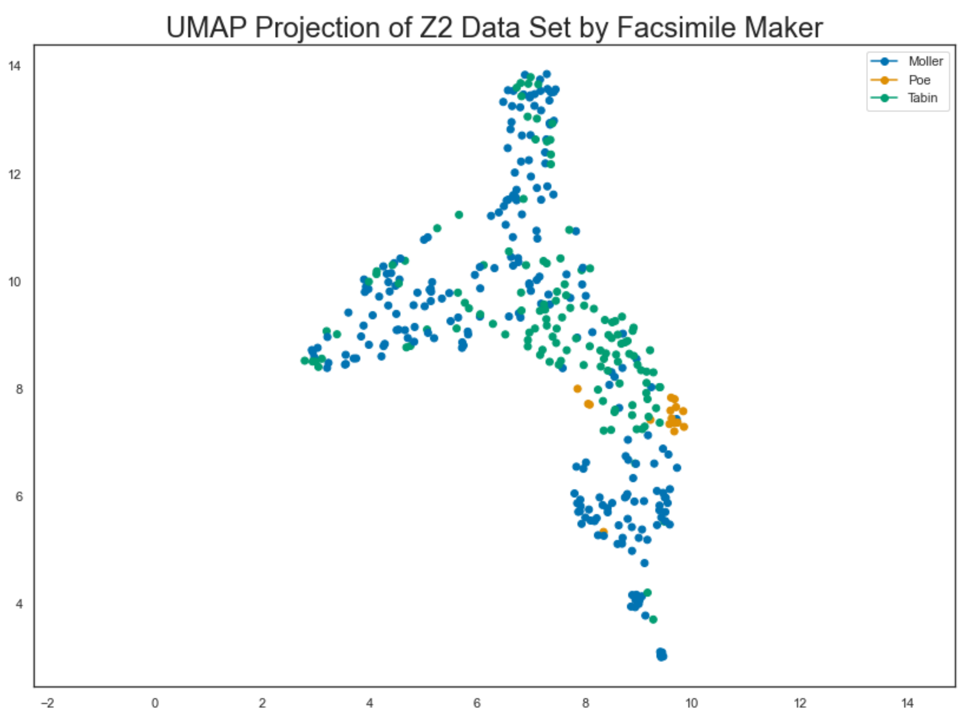

UMAP Projection of Z1 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
6
4
2
0
−2
−2
0
2
4
6
8
10
12

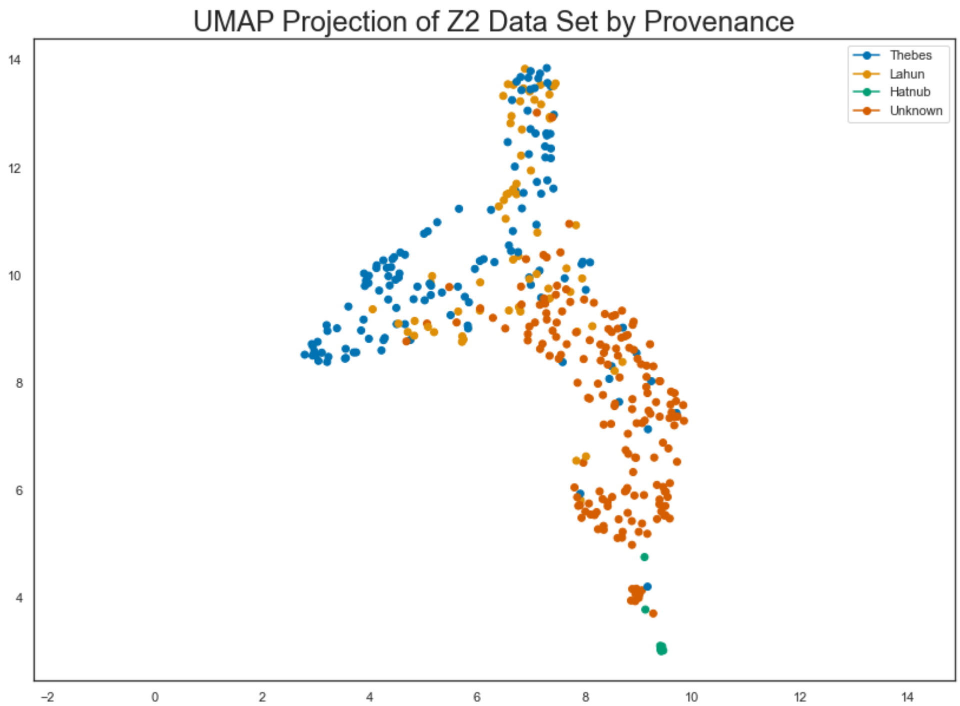

UMAP Projection of Z1 Data Set by Facsimile Maker
Moller
Poe
Tabin
6
4
2
0
−2
−2
0
2
4
6
8
10
12

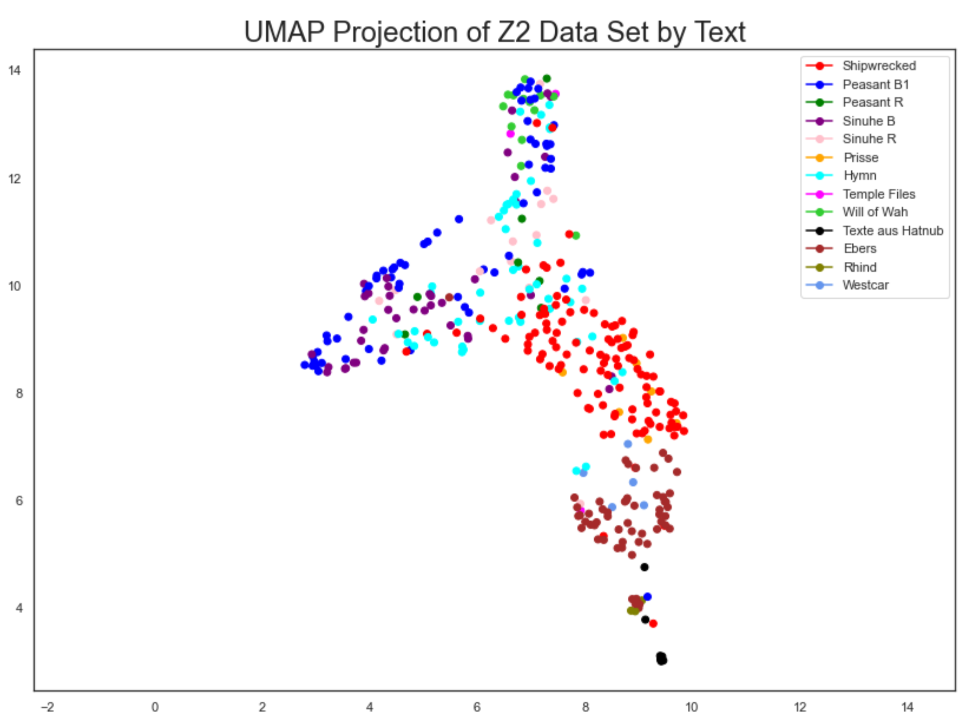

UMAP Projection of Z1 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
6
4
2
0
−2
−2
0
2
4
6
8
10
12


UMAP Projection of Z1 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
6
4
2
0
−2
−2
0
2
4
6
8
10
12


UMAP Projection of Z2 Data Set by Genre
Literary
Instruction
Hymn
Administrative
Inscription
Medical
Mathematical
14
12
10
8
6
4
-2
0
2
4
6
8
10
12
14


UMAP Projection of Z2 Data Set by Facsimile Maker
Moller
Poe
Tabin
14
12
10
8
6
4
-2
0
2
4
6
8
10
12
14


UMAP Projection of Z2 Data Set by Provenance
Thebes
Lahun
Hatnub
Unknown
14
12
10
8
6
4
-2
0
2
4
6
8
10
12
14


UMAP Projection of Z2 Data Set by Text
Shipwrecked
Peasant B1
Peasant R
Sinuhe B
Sinuhe R
Prisse
Hymn
Temple Files
Will of Wah
Texte aus Hatnub
Ebers
Rhind
Westcar
14
12
10
8
6
4
-2
0
2
4
6
8
10
12
14