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Digital Palaeography*

Mark Aussems, Axel Brink

Abstract

This article seeks to explore new digital ways of distinguishing between scribal hands in medieval manuscripts. An analysis of traditional palaeographical approaches to hand identification will be followed by a discussion in which attention will be paid both to the use of computer software to enhance existing methods of scribal identification, and to the benefits of *Quill*, an innovative automatic writer identification tool. A case study involving a manuscript of the collected works of Christine de Pizan (London, British Library, Harley 4431) will serve to demonstrate that traditional palaeographical methods of analysing scribal hands can greatly benefit from the use of specialised computer software.

Zusammenfassung

Der Beitrag versucht, neue digitale Wege zu erkunden, um Schreiberhände in mittelalterlichen Handschriften zu unterscheiden. Nach einer Analyse des traditionellen paläographischen Ansatzes zur Handidentifikation diskutiert er sowohl die Möglichkeiten, bisherige Methoden mit dem Computer zu verbessern als auch den Nutzen von *Quill*, eines innovativen Werkzeugs zur automatischen Schreiberidentifikation. Eine Fallstudie einer Handschrift der gesammelten Werke der Christine de Pizan (London, British Library, Harley 4431) demonstriert, dass traditionelle paläographische Methoden der Schreibhandanalyse von der Anwendung spezialisierter Computersoftware deutlich profitieren können.

1 Introduction

The identification of scribal hands in medieval manuscripts is one of the most important problems in the discipline of palaeography. Over the years, experienced palaeographers have created many methodological approaches to scribal identification, each with its own advantages and inconveniences. These methodologies are without exception based

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on what could be called traditional palaeography. They promote the use of traditional palaeographical tools such as protractors and set squares to measure letter heights and widths, distances between characters, margins, and angles of inclination. Furthermore, they consider certain immeasurable features of a medieval hand—such as *ductus*, writing speed, and the number and types of abbreviations that are used—as criteria that can be used to distinguish between scribal hands.

In recent years, a significant number of digitisation projects involving medieval manuscripts have seen the light of day. This ever-increasing corpus of digital manuscript images has made palaeographers, codicologists, philologists, and art historians around the globe aware of the advantages which it may generate for the study of manuscripts. The availability of high resolution manuscript images has also inspired computer scientists to contribute to the palaeographical discussions about hand identification. This cross-fertilisation of information technology and palaeography, albeit in a preliminary stage, has produced some interesting outcomes, which have not yet received the attention they deserve.

The present article seeks to analyse several of the aforementioned traditional methods of scribal identification in the light of the new digital possibilities within the field of manuscript analysis. To what extent will traditional palaeography be able to benefit from recently developed computer software? Can palaeographical measurements be carried out faster and more accurately with the arrival of the computer on the palaeographer's desk? Are there new possibilities for manuscript research to be discovered that had not been possible before?

Our attention will centre on *Quill*, a promising outcome of the recent involvement of computer experts within the field of palaeography. An analysis of the scribal differences in a manuscript containing works by the French author Christine de Pizan (*ca* 1364 – *ca* 1430)—whose manuscripts are subject to heated discussions between specialists about the number of hands that can be distinguished in them—will be carried out conjointly by *Quill* and through a traditional palaeographical method. The results of this case study can provide useful insights into the benefit of automated and digital recognition of scribal hands to the discipline of palaeography.

2 Traditional Palaeography

When, around the turn of the seventeenth century, the Benedictine monks of the Congregation of St. Maur started cataloguing specimens of handwritten texts, they little knew that some three hundred years later, their approach to manuscript texts would become one of the most important auxiliary sciences within the discipline of History. Although he did not coin the term 'palaeography', Jean Mabillon was the first scholar to create a set of chronologically ordered samples of handwriting (Mabillon). Mabillon's fellow-brothers Bernard de Montfaucon, Charles-François Toustain, and René-Prosper Tassin continued and expanded his work, thus creating the first systematic survey of handwriting (Montfaucon; Toustain and Tassin). From the second half of the nineteenth century onwards, this approach to medieval manuscripts became popular and was studied extensively by, among others, Léopold Delisle, Ludwig Traube, Wilhelm Wattenbach, and, in more recent times, Jean Mallon, Bernhard Bischoff, Léon Gilissen, and Albert Derolez.[1]

Within this palaeographical framework, more and more attention was paid to the history—or the *archaeology*—of the medieval book. Under the influence of Alphonse Dain, Charles Samaran, François Masai, and Léon Delaissé, the discipline of codicology was created, its objective being to study the history and the production of the medieval codex (Dain; Delaissé). This interest in the medieval book as a material and cultural object brought about a change in palaeography. Influenced by codicological studies on the functioning of medieval scriptoria, palaeographers became more and more interested in distinguishing between medieval hands in a single text or a corpus of texts rather than between different scripts. This was the beginning of a structured and logical analysis of medieval handwriting as a phenomenon, influenced not only by external factors such as the education of the scribes, the size and material of the quill, and the writing support, but also by the scribes' own subconscious execution of a particular script.

Over the last fifty years, a number of methods have been created that can be used to distinguish between multiple hands that make use of the same script to transcribe a text or a corpus of texts. In 1952, Jean Mallon, in his work *Paléographie romaine*, introduced a list of seven aspects of a medieval hand that should be taken into account when distinguishing scribal hands (Mallon 23):[2]

- the *form*, the morphology of the letters;
- the *angle of writing* in relation to the line for writing;
- the *ductus*;
- the *modulus*, the dimensions of the letters;
- the *contrast*, the difference in thickness between hair lines and shadow lines;
- the *writing support*;
- the *internal characteristics*, the nature of the text.

This list of what could be called *differentiators* has been used by other palaeographers and has become the basis of later methodologies. Léon Gilissen adapted and developed Mallon's differentiators in his 1973 work *L'expertise des écritures médiévales.* Gilissen drops the last two differentiators in Mallon's list in favour of another, called *style*, by which he means "une manière d'être qui se répercute sur tous les éléments de l'écriture,

[1] See the Bibliography at the end of this article for references to works of these scholars.
[2] See also Stokes in this volume.

qui affecte et qui marque le phénomène entier" [a feature that has repercussions on all aspects of writing, thus affecting and marking the entire phenomenon] (50). Furthermore, Gilissen tries to make the methodology more objective and more accurate by expressing some of the differentiators in numerical values rather than by giving lengthy descriptions. In 1995, the Dutch palaeographer Jan Burgers surveyed the existing methodologies for hand identification, including some interesting publications in the field of forensic analysis (e.g. Michel; Hardy and Fagel). He combined these approaches in what could be called the *Burgers methodology*, a successful method of differentiating between scribal hands in charters (Burgers). In recent years, Mark Aussems has shown that this method can—with some adjustments—be applied to scribal hands in medieval manuscripts (Aussems 2006; Aussems 2008). He also coined the term *scribal fingerprint* to denote a set of objective, accurate, and quantifiable characteristics that are unique to one particular scribal hand (Aussems 2006 10). To this extent, he emphasises the benefit of computers and specific computer software to the quantitative study of medieval handwriting (Aussems 2007; Aussems 2008).

3 Digital Palaeography

The expression *digital palaeography* was coined by Arianna Ciula in her 2005 article 'Digital palaeography: using the digital representation of medieval script to support palaeographic analysis' and was created as a result of cross-fertilisation between the academic disciplines of Palaeography, Computing, and Artificial Intelligence. The many digitisation projects involving medieval manuscripts have undoubtedly contributed to this collaboration. By way of a definition, digital palaeography is the discipline that makes use of computers and computer software to analyse classical and medieval handwriting. It thereby relies on the quantitative aspect of palaeography; the values attached to the aforementioned differentiators need to be turned into numerical data. Of the list provided in Aussems 2006, four differentiators can be expressed as numerical values: the *angle of inclination*, the *angle of writing*, the *modulus*, and the *degree and type of cursivation of connecting characters*.

The advantages of numerical data lie in the fact that they enable rapid analysis by computer software, and enable—and indeed even facilitate—a comparison between different hands that is based on objective and comparable data rather than on 'verbal' descriptions of a hand. These advantages become clear when we compare the two examples below: a verbal description of X, one of the hands found in the original manuscripts of works of Christine de Pizan and, in Figure 1, part of a numerical description of one of the hands in Christine's *Queen's Manuscript* (London, British Library, Harley 4431).

5. Modulus

a. Average height of the short letters (H) – letter i

	1	2	3	4	5	6	7	8	9	10	**Average**
fol/line	10a/13	10a/17	10a/35	10b/6	10b/34	10c/10	10c/30	10d/6	10d/22	10d/22	
measured word	*mainte*	*sepmaines*	*certaines*	*qui*	*puis*	*tainte*	*desmis*	*puis*	*depuis*	*auient*	---
height (mm)	*2,3*	*2,3*	*2,7*	*2,0*	*2,5*	*2,7*	*2,3*	*2,7*	*2,3*	*2,3*	***H=2,4***

b. Average height of the ascending letters (A) – letter l

	1	2	3	4	5	6	7	8	9	10	**Average**
fol/line	10a/22	10a/32	10b/8	10b/17	10b/31	10c/7	10c/31	10d/6	10d/28	10d/37	
measured word	*malades*	*doulours*	*tele*	*oublier*	*uouldroie*	*doulce*	*soulas*	*celer*	*p^{er}illeux*	*solas*	---
height (mm)	*3,7*	*3,3*	*3,5*	*3,3*	*3,3*	*3,3*	*3,5*	*3,5*	*3,5*	*4,0*	***A=3,5***

c. Average width of a single letter form (W)

	1	2	3	4	5	**Overall**
fol/line	10a/8	10b/4	10b/24	10c/18	10d/30	
length (mm)	*75*	*65*	*85*	*60*	*85*	---
number of characters	*37*	*34*	*40*	*29*	*38*	---
width single character (mm)	*2,0*	*1,9*	*2,1*	*2,1*	*2,2*	***W= 2,1***

d. Line spacing (S)

folio	10b	distance between first and last line of writing (mm)	230	number of lines minus one	37	***S= 6,2***

Figure 1. A (slightly altered) numerical description of the *modulus* of hand A in manuscript London, British Library, Harley 4431; Aussems 2006, Appendix H, p. 6.

> Mieux vaut caractériser cette main par des tendances que par des formes : en effet, beaucoup plus habile que les deux autres, elle est, par voie de conséquence, également plus changeante, adoptant des styles d'écriture assez variés qui relèvent tous, néanmoins, de la cursive livresque. La constante la plus remarquable de X, c'est une exubérance, un goût pour les grandes envolées de la plume se déployant en un foisonnement de boucles et de volutes et faisant alterner pleins et déliés. (Ouy and Reno 1980 226)

Another advantage of the use of computer software in the field of quantitative palaeography is the increase in accuracy of the measurements that are carried out within a manuscript. Whereas traditional palaeographers had to revert to the use of a ruler or a set square to measure letters on the pages of a manuscript—thereby obviously having to operate very circumspectly so as not to damage the codex—this rather painstaking task can nowadays be executed quickly, safely and accurately by means of special imaging software that has a built-in measuring tool which allows palaeographers to carry out digital measurements.[3]

So far, we have focused on the added value of computers for the field of palaeography in its traditional form. However, in recent years there have been a number of very interesting developments within the disciplines of Artificial Intelligence and Computing which have the capacity not only to contribute to current palaeographic methodologies, but also to enhance or renew them, while *en passant* changing the way we look at scribal hands and medieval handwriting. One of the most promising initiatives in this context is *Quill*, a program to automatically compute writer features in historical documents.

4 *Quill*: A Different Approach to Digital Palaeography

Researchers at the Artificial Intelligence department at the University of Groningen have shown that one of their established automatic techniques can be used to identify medieval scribes (Bulacu and Schomaker 2007). Now, as part of the NWO (The Netherlands Organisation for Scientific Research) project TRIGRAPH,[4] a new automatic technique is emerging that focuses on historical handwriting in particular: the *Quill Dynamics Feature* (or: *Quill*).[5] Although the paper describing this technique in detail is expected to appear only in 2010, *Quill* is already contributing to several historical research initiatives.

Quill relies on the principle that writing instruments with an oblong contact surface (such as a quill) introduce writer-specific variation in the width of the ink trace. In a scanned document, *Quill* measures "the relation between the local direction and width of the ink traces" (Brink et al. 2010, section I). This is done by first determining the contours of the text: trajectories of dark (ink) pixels adjacent to light (parchment) pixels. Then, the contours are traversed counter-clockwise, while performing two measurements at every pixel: the direction of the ink and its width. This results in thousands of direction-width measurements for a document. The measurements are agglomerated in a *Quill Probability Distribution (QPD)*, which expresses the frequency at which each ink width was produced at each ink direction. Such a QPD is specific for each hand.

The intended use of *Quill* is to be incorporated in a system that performs writer identification. Given a query document, such a system can search a corpus of handwritten

[3] Computer programs like *Adobe PhotoShop* and *The GIMP* (short for: *GNU Image Manipulation Program*) already have built-in tools to measure distances and angles on-screen.

[4] The TRIGRAPH project (2005–2009) aims to improve automatic writer identification methods for forensic application by combining manual, semi-automatic, and fully-automatic methods. Recent developments have broadened the project to include historical handwriting as well.

[5] See Brink et al. 2010. Since this article is forthcoming, references will be given to its numbered sections rather than to page numbers.

documents by comparing the handwriting of the query document to that of all the other documents. It then returns a sorted list of documents with similar handwriting. The comparisons are based on an automatically computed feature such as a QPD, computed by *Quill*. In this way, given a document, a *hit list* is suggested of other documents that could have been written by the same hand. Although never 100% correct, this method works very well and saves the palaeographer a lot of time.

Writer identification by computing a hit list is not the only possibility. Another option is to apply a *clustering technique* to distinguish clusters (groups) of documents with similar handwriting, based on the QPD. This is very interesting when working with a corpus of texts, where it is known how many scribes were involved in their transcription—the clustering technique can be used to order the documents as if they were written by *k* scribes, where *k* is a number chosen by the user. An important issue is that if the handwriting in the analysed documents is quite similar, clustering will yield different groups in repeated executions. The obvious reason is that a strict separation is hard to make in such a case. A possible solution is to repeat the clustering many times while keeping track of the number of times every pair of documents were clustered into the same group.

5 Case Study

By means of an experiment, *Quill* was tested on a set of images of Dutch charters (1299-1328) in an earlier stage and proved to yield results that equal or surpass those of comparable computer programs (Brink et al. 2010, sections V and VI).[6] In the present article, we will test *Quill* on a different set of documents, but also examine whether the results obtained by *Quill* match those yielded by a palaeographical analysis of the same set of documents. Subject of this case study are two parts of the famous *Queen's Manuscript* (London, British Library, Harley 4431), a collection of thirty works by French author Christine de Pizan produced in the closing months of 1413 and presented to Queen Isabeau of France in January 1414 (Laidlaw 2005). The manuscript is unique in that for many of Christine's texts—which she often revised and corrected as they went through multiple 'editions'—Harley 4431 constitutes the last known version. Moreover, research conducted on the number of scribes that were involved in the transcription process of the codex has yielded divergent conclusions: whereas Gilbert Ouy and Christine Reno conclude that the Queen's Manuscript has been transcribed in its entirety by a single scribe (Ouy and Reno 1980), Sandra Hindman, James Laidlaw and others have taken a different stand (Hindman 1983, Laidlaw 1983 and 1987, Aussems 2006).

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[6] Comparable applications include *Hinge* (Bulacu and Schomaker, Text-independent Writer Identification) and *Fraglets* (Schomaker et al. 2004).

Of particular interest in this case is quire 6 of the Harley MS, which is discussed in detail in Laidlaw 1987 and Aussems 2006. This quire contains folios 44 to 50, 50bis, 50ter, 51 and 52. It was originally conceived as a regular quaternion (44-47 / 48, 50ter, 51-52), but enlarged by a binion of which the third leaf was subsequently cancelled (49-50 / *, 50bis).[7] What is more, folios 50bis and 50ter are left blank. Figure 2 is a graphical representation of the structure of this quire. However, it is not just the codicological composition of quire 6 that interests us. In terms of scribal hands, the folios of this quire are witnesses to what seems to be a very intriguing change of hands. The first two folios of this quire—44, 45, and 46a—have been transcribed by the hand we have come to call B. Column 46b, however, seems to have been written not only in a paler ink, but also by a different hand, which we will call A. The verso of folio 46 is, again, written by hand B, who continues up to and including folio 48a. Folios 48b up to and including 51a, then, seem to be copied in hand A, after which B probably takes over again and finishes the quire. Figure 5 presents this change of hands by means of a diagram, and Figures 3 and 4 show folios 48r and 51r respectively, which clearly demonstrate the alleged change of hands from B to A and vice versa.

By means of a case study, we will subject these folios to a thorough palaeographical examination, carried out both by *Quill* and by using a computer-enhanced traditional approach. To this extent, we divided the folios into sections A and B, each corresponding to their respective assumed scribe. Consequently, we took samples of each hand by selecting parts of the text that do not contain miniatures, illumination or decoration.[8] The final result of this operation is seven samples of hand A and seven samples of hand B, each amounting to 170 lines of text (see Figure 6).[9] All text specimens were taken from columns b and c of the aforementioned folios only, because the text in columns a and d always appears slightly curved and oblique in the photos due to the impossibility of fully opening the large codex. Thus, we eliminate the possibility that the distorted text in columns a and d might corrupt our test results.

5.1 Traditional Palaeography

The 'traditional' palaeographical analysis involved an examination of the angle of inclination, and the height of the ascending characters of the handwriting in each of the samples. It was carried out by using the computer program *GIMP* to measure distances and angles according to the methodology as set out in Aussems 2006. The angle of

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[7] In the two schematic representations of the quires, the sign / indicates the heart of the quire; * means a cancelled folio.

[8] In order for *Quill* to be as accurate as possible, every element that does not constitute a part of the text needs to be removed from the text that is to serve as input.

[9] The samples were taken from the following folios. Hand A: 46b:25 (lines), 48b:31, 48c:15, 49b:36, 49c:21, 50b:19, 50c:23. Hand B: 44b:27, 45b:10, 46c:22, 47b:28, 51c:30, 52b:39, 52c:14.

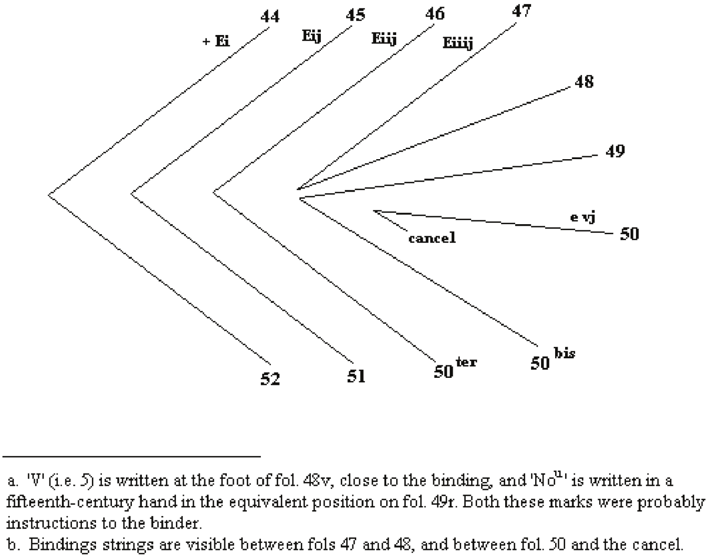

Figure 2. Graphical representation of the codicological structure of quire 6. Source: Aussems 2006 85; Laidlaw 1987 63.

inclination was measured at the right hand side of ten different shafts of the character *l*. The modulus consists of four different elements, one of which is the height of the ascending characters: it was determined by measuring ten characters *l*.[10] Finally, the measurements of each hand were averaged. The results are presented in Figure 7.

What becomes clear—not only from the averages presented above, but also from the results of each separate sample—is that there seems to be a substantial difference between hand A and hand B. Whereas the ascenders in the handwriting of scribe A are almost at right angles to the base line, those in hand B seem to be on average 10° out of the vertical. Furthermore, these ascenders are generally 0.5 mm larger in hand B. This is quite a significant difference, given the small standard deviations and the fact that the average numbers were calculated on the basis of 70 measurements for each hand.

[10] An inconvenience related to the images of Harley 4431, taken by the British Library photographic staff, is that the distance between the camera and the manuscript was not fixed, meaning that the readings—be they in millimetres or in pixels—cannot be compared. In order to overcome this problem, we measured the distances in pixels and subsequently converted them to millimetres by using the ruler placed within each photograph, giving us the exact distance in millimetres.

Figure 3. Folio 48r of the Queen's MS, showing hands B (column a) and A (column b). © British Library Board. All Rights Reserved. MS Harley 4431.

Figure 4. Folio 51r of the Queen's MS, showing hands A (column a) and B (column b). © British Library Board. All Rights Reserved. MS Harley 4431.

5.2 Quill

The text fragments were also subjected to a clustering experiment. To be specific, the clustering technique used is called *k-means*. As anticipated, the handwriting in the documents is too similar for a reliable instant grouping, thus the clustering was repeated 10,000 times. Figure 8 shows how often each pair of documents was classified in the same group, on a scale of 0 to 1.

The figure shows that most documents that were labelled "A" were grouped together, as indicated by numbers between 0.5 and 1.0 in the upper left block, coloured light grey. The same applies to most texts labelled "B", in the lower right block. Thus the automatic labelling using repeated clustering in two groups agrees to a large extent with the results of the manual determination described above.

However, there are two exceptions. Firstly, document 2—representing folio 48c and supposedly written in hand A—seems to belong to group B, given its high frequency numbers in the dark grey upper right and lower left blocks. Secondly, document 9 (hand B, f. 46c) does not seem to belong to either group A or B, as is demonstrated by

Hand A	Hand B	Contents
46b	44abcd 45abcd 46a 46cd 47abcd 48a	*Aultres balades*
48bcd 49abcd 50abcd 51a		*Une complainte amoureuse* *Encore aultres balades*
	51bcd 52abcd	*Epistre au dieu damours*

Figure 5. Distribution of hands in quire 6 of the Queen's MS. Folios 50bis and 50ter are not mentioned here, because they are blank.

the frequency numbers around 0.5 in both lower blocks. It must therefore be concluded that both documents are different from the other documents in their supposed group only regarding the relation between the direction and the width of the ink trace.

There are many possible explanations of this deviation. Obviously, it is possible that the initial identification of the scribal hands in the documents was not correct. Although the evidence presented by the *Quill* results is strong, a manual codicological examination of both folios in the MS Harley 4431 has yielded no evidence which corroborates this claim. A thorough palaeographical analysis of the aforementioned quire 6—taking into account specimens of every text column—may shed new light on this interesting case. A second explanation could be that the tip of the quill used by the scribe was in a different condition, possibly caused by trimming the pen. A further issue underlying the occurring deviation might be that the scribe returned to his work in the scriptorium after an (extended) break. It is well-known that a scribe's hand needs to 'warm up' before being able to execute its regular, flowing style.

The results generated by *Quill* provide a new, fresh insight into the questions and issues surrounding the scribal hands that are to be distinguished in the *Queen's Manuscript* in general and in its sixth quire in particular. It is greatly reassuring to observe that *Quill*'s classification of the major part of the documents matches perfectly with those reached through a traditional palaeographical analysis.

6 Conclusion

The palaeographical tests carried out on quire 6 of the Harley MS by means of a computer-enhanced 'traditional' method and by using *Quill* not only yield strikingly

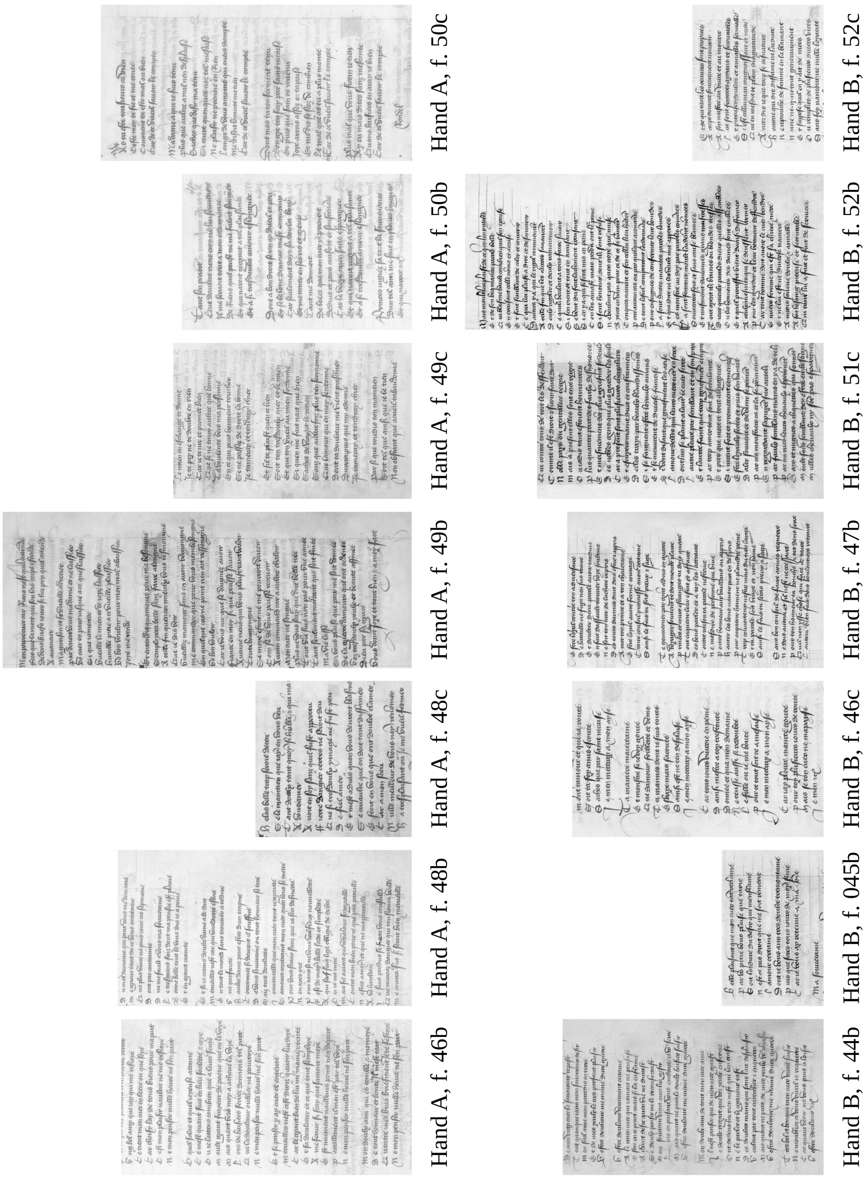

Figure 6. Overview of the fourteen samples used in the case study. MS Harley 4431.

	Hand A	Standard deviation A	Hand B	Standard deviation B
Angle of inclination	89°	1.5°	80°	2.9°
Height of ascending letters	3.4 mm	0.24 mm	3.9 mm	0.23 mm

Figure 7. Results of the palaeographical analysis of quire 6 of the Queen's MS, including the corresponding standard deviations.

		Doc0	Doc1	Doc2	Doc3	Doc4	Doc5	Doc6	Doc7	Doc8	Doc9	Doc10	Doc11	Doc12	Doc13
Doc0	A_046b	1.00	0.99	0.37	0.93	0.97	0.78	0.88	0.15	0.20	0.58	0.38	0.20	0.16	0.23
Doc1	A_048b	0.99	1.00	0.39	0.92	0.98	0.77	0.89	0.16	0.21	0.59	0.37	0.19	0.15	0.24
Doc2	A_048c	0.40	0.39	1.00	0.41	0.37	0.26	0.28	0.75	0.72	0.41	0.98	0.81	0.76	0.75
Doc3	A_049b	0.93	0.92	0.41	1.00	0.94	0.85	0.87	0.22	0.17	0.55	0.43	0.26	0.23	0.20
Doc4	A_049c	0.97	0.98	0.37	0.94	1.00	0.79	0.91	0.18	0.23	0.61	0.39	0.21	0.17	0.26
Doc5	A_050b	0.78	0.77	0.26	0.85	0.79	1.00	0.88	0.07	0.02	0.41	0.28	0.11	0.08	0.06
Doc6	A_050c	0.88	0.89	0.28	0.87	0.91	0.88	1.00	0.11	0.14	0.53	0.30	0.13	0.10	0.18
Doc7	B_044b	0.15	0.16	0.75	0.22	0.18	0.07	0.11	1.00	0.95	0.57	0.77	0.95	0.99	0.91
Doc8	B_045b	0.20	0.21	0.72	0.17	0.23	0.02	0.14	0.95	1.00	0.62	0.74	0.91	0.94	0.96
Doc9	B_046c	0.58	0.59	0.41	0.55	0.61	0.41	0.53	0.57	0.62	1.00	0.43	0.60	0.56	0.65
Doc10	B_047b	0.38	0.37	0.98	0.43	0.39	0.28	0.30	0.77	0.74	0.43	1.00	0.83	0.78	0.77
Doc11	B_051c	0.20	0.19	0.81	0.26	0.21	0.11	0.13	0.95	0.91	0.60	0.83	1.00	0.96	0.97
Doc12	B_052b	0.16	0.15	0.76	0.23	0.17	0.08	0.10	0.99	0.94	0.56	0.78	0.96	1.00	0.90
Doc13	B_052c	0.23	0.24	0.75	0.20	0.26	0.06	0.18	0.91	0.96	0.65	0.77	0.95	0.90	1.00

Figure 8. Frequencies of same-group occurrences after clustering into two groups 10,000 times, based on *Quill.* The numbers show how often each pair of two texts was automatically clustered in the same group, on a scale of 0 to 1. High numbers indicate that the documents were probably written by the same hand.

similar results, but also demonstrate the successful implementation of computer software within the field of palaeography. On the one hand, the case study proves that the traditional palaeographical methods of analysing scribal hands can greatly benefit from the use of computer software which contains built-in measurement tools. On the other hand, we have demonstrated that *Quill*—which is being continuously improved—provides palaeographers with an interesting new approach to distinguishing between scribal hands.

The approach taken by the developers of *Quill* is innovative not only because of its use of the computer as a true aid to the experienced palaeographer, but also because of the way the program analyses medieval handwriting. Of the differentiators mentioned in section 2 of the present article, none corresponds exactly with *Quill*'s approach of using the relation between the width of the ink trace and its direction as a discriminating factor in the search for scribal hands. This new differentiator makes an extremely valuable contribution to palaeography.

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