The Case of the Disappearing Ox: Seeing Through Digital Images to an Analysis of Ancient Texts

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ABSTRACT
There are numerous settings where people examine, scrutinize and discuss the details of images in the course of their work. In most medical domains, scans and x-rays are used in the diagnosis of cases; in most areas of science, methods of visualization have been adopted to assist in the analysis of data; and images of different kinds are critical for many research fields in the social sciences and humanities. It is not surprising that recently technologies have been proposed to assist with the analysis and examination of images. In this paper, we consider requirements for technologies in a rather distinctive domain of research, the classics. Drawing upon an analysis of the detailed ways in which classicists work with digital images, we discuss the requirements for systems to support researchers in this domain, and also provide further considerations on the general development of image processing technologies and visualization techniques.

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Workplace studies, Ethnomethodology, Interaction analysis, CSCW, Requirements engineering, Usability.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Computer-supported cooperative work. H4.3.

General Terms
Human Factors, Design.

INTRODUCTION
The last 10 years have seen remarkable technological developments to support scientists and scientific work. The processing power made available through supercomputers, as well as applications and databases that can be shared and distributed over many sites and institutions offer the potential to transform science. Such initiatives, originally termed collectively e-Science or Cyberinfrastructure, have now been broadened from a focus on the life sciences to encompass research in general, whether in social sciences or humanities. However, despite the considerable investment in infrastructures, many of these technologies have not yet been widely deployed [20]. Even in cases where technical successes have been achieved, and where potential users are willing to experiment with new systems and even build their own applications, a critical barrier for greater uptake and use of such technologies has been associated with usability [21, 31].

As with other more conventional domains, in order to develop interfaces to, and design interactions that are appropriate for scientists and researchers, it is necessary to understand their working practices. Although these might be complex and appear particular to the domain in question, analyses of practices can contribute to our understanding of general issues of concern to design. In this paper we consider a quite distinctive setting of research, a domain where classicists analyse in detail the properties of images that were taken of damaged and degraded ancient manuscripts. Drawing from a video-based ethnographic study, we discuss requirements for technologies to support how practitioners view images. We also raise more general considerations for the design of visualization and image processing systems.

BACKGROUND
It is not just in applications associated with e-Science that an understanding of viewing practice is critical for the design and deployment of new technologies. There are also research areas within computer science more generally that focus on the design of information visualisation and enhanced digital imaging technologies. Much of the work in this area has focused on developing algorithms for image feature detection such as content-based image retrieval of shape, texture and color as well as text-based retrieval using

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ontologies and classification schemes for image description [11]. Recent research has investigated novel support for navigation for example, by developing techniques to present magnified digital images [14] and augmenting visual data through haptic interfaces [26]. There have, however, been few naturalistic studies investigating how researchers and scientists interact with such systems. The studies that have been undertaken tend to focus primarily on browse and search in digital image repositories [e.g. 9]. It seems therefore worth investigating whether naturalistic studies of researchers and scientists viewing enhanced images can help inform the design of innovative imaging and visualization techniques that are appropriate to their needs.

There are numerous professional settings where people have to examine, scrutinize and discuss the details of visual images. In most medical domains, scans, x-rays and the like are used in the diagnosis of complex cases [15]; in most areas of science, various methods of visualization have been adopted to assist in the analysis of data [13]; and images of different kinds are critical for many research fields in the social sciences and humanities [8]. In this paper, we consider a domain involving the analysis of a specific kind of image, for researchers involved in an area of humanities research - the classics. Although, there are notable exceptions, for example, the development of 3D computer modeling to help art historians identify features in a painting [2] or to assist archaeologists to assemble broken fragments of artefacts [32], investigating how new image processing technologies can support researchers in the humanities has largely been neglected in the fields of e-Research or indeed in fields associated with Human-Computer Interaction.

In settings where images are viewed collaboratively, studies have revealed that it is not only important that participants identify features or objects within images for their colleagues, but also *how* such features are identified. When analyzing the detail of a scene or image, participants animate through their talk, body conduct and gaze direction, the features they are discussing: their conduct being shaped through their moment-to-moment collaboration with others [12]. When trying to support such practices through technology, particularly for participants who may be remote, a number of researchers have considered how to display such conduct across distributed sites [16, 17]. Given the complexity of trying to capture embodied action and material conduct, these efforts have tended to focus on re-producing particular features of gestures, like the movement of a cursor across an image or the real-time production of a mark of a pen [e.g. [8].

BUILDING TECHNOLOGIES FOR CLASSICISTS

One of the principal ways in which technological support is being developed for researchers in the humanities in the United Kingdom is through a programme of building Virtual Research Environments (VREs). A key aim of these technologies is to provide an environment that encourages researchers to collaborate across distributed locations. As with many initiatives of this kind, a number of investigative projects have been set up where it has been suggested that advanced technologies have the potential to enhance research. Two of these, the VRE for the Study of Ancient Documents (VRE-SDM), and the e-Science and Ancient Documents (eSAD) projects consider the possibilities of using novel image processing technologies to support the work of classicists. These projects seek to identify the requirements of documentary, textual and manuscript scholars through a combination of an analysis of their practices in conjunction with the development of technology prototypes.

The use of image processing in the fields of epigraphy; the study of ancient inscriptions and papyrology; the study of ancient texts written on papyrus or writing tablets is not that new. For the past 20 years infrared image processing techniques have been used to improve the legibility of ancient texts incised on wooden surfaces. More recently a new technique has been introduced. Digital images of a physical object are taken using variable directional lighting, after which a series of algorithms are applied to the image that analyse the shadows cast across the surface at a low elevation [19]. This enhances edge detection of the markings within the image, making it easier to identify the strokes that constitute each letter. In addition to this, algorithms are being developed that remove additional 'noise' from an image. The eSAD project seeks to develop technologies and techniques that can make these enhanced images available to researchers, allow them to manipulate the images and even to develop tools that can assist in their analysis activities [4]. For example, image processing algorithms, such as brightness and contrast adjustment, illumination correction, and complex techniques for stroke detection and woodgrain removal are offered as features wrapped in one or more web services. The project is exploring the development of an Interpretation Support System (ISS) for the day-to-day reading of ancient documents that aims to keep a record of how the documents are transcribed and interpreted [7, 22]. Such support systems require the implementation of capabilities [28] such as: databases of standard letter shapes; algorithms for the automatic detection of letters within digital images; letter frequency detection; and character lists aggregated from both ancient manuscripts and the research literature. Much of the content for these components will come from the experts. From these resources it may even be possible to estimate the statistical likelihood of certain patterns in the texts matching particular letters and words: in other words automating some of the analysis.

In this paper we consider the practices of a number of expert classicists as they analyse digital images of an ancient manuscript, and the consequences for systems being developed for the classicists and for the design of intelligent and distributed technologies to support the analysis of

images in general. For this we principally draw on video-recordings of the classicists as they analyse one particular manuscript that has been enhanced through image processing - the Tolsum Tablet.

AN ANCIENT TEXT: THE TOLSUM TABLET

The Tolsum tablet is a Roman writing board found in 1914 in a mound in Tolsum in Friesland, a northern province of the Netherlands and dates back to the 1st Century AD. It is an inscribed wooden stilus tablet with a shallow recess that was filled with wax. To use the writing tool, incisions were made in the wax by a scribe. The wax could be smoothed over and reused for rewriting. In most tablets the original wax coating no longer exists. In such cases classicists try to reconstruct the text by deciphering the scratches left by the stilus in the wood after it penetrated the wax [5]. However, this is not always feasible when scribes re-use tablets many times, resulting in the marks from several texts appearing on the tablet.

The Tolsum tablet was first translated by the scholar Vollgraff in 1917. As is typical of this type of tablet, the front (Figure 1) describes its purpose (e.g. a loan, will, shopping list, etc.) and, in the Tolsum tablet, includes 10 lines of text with information relevant to the dating of the tablet (e.g. the names of Roman consuls). The back of the tablet has the signatures of participants and witnesses and includes 6 lines of text. In this study we focus on the activities involved in analysing the front of the tablet. Although marks can still be seen on the surface of the tablet, in places they are indistinct and the characters they form are hard to determine (as can be noticed in Figure 1).

An example of Vollgraff's transcription of text is highlighted in line 5, Figure 1, where he reads:

EMI TESTE CESIDIO C(ENTURION)I
(line 5 of the Tolsum tablet as translated by Vollgraff in 1917)

This loosely translates from Latin as *the witnessing of a sale in a certain amount*. Above it, in line 4, Vollgraff translated the line as 'RITE UTI LICET BOVEM', referring to an ox ('BOVEM'). Hence, Vollgraff interpreted the entire text as referring to the sale of an ox between a local resident and a Roman.

For many years this tablet was the northernmost of its kind to be translated and quite important as it could be related to a revolt in Frisia in AD 28, associated with the taxation of ox hides and reported by Tacitus [3]. This connection clearly depends on achieving a degree of certainty about the dating of the tablet that scholars had variously suggested could be between AD 29 and 116.

For the classicists involved in our project, it seemed that image processing could assist with a re-examination of the

Figure 1. The Tolsum tablet (front) with line 5 highlighted.

tablet, particularly with regard to a more accurate dating. As can be noted from Figure 1, the text of this tablet is barely legible. In traditional practice, when working directly with a wooden tablet, classicists will attempt to make the text legible by tilting the tablet in various directions in order to steer the ways in which light and shadow are cast upon the incised surface. This tilting of the tablet in relation to lighting may make letters, words and lines of text legible [6]. With digital images, variable directional lighting can be simulated to some extent. Moreover, image processing can also reduce the visibility of the woodgrain of the tablet, making it easier to distinguish the marks that are made on it [27].

With the introduction of enhanced digital images, classicists could now work collaboratively over large projected images of the manuscript displayed on a screen, rather than working with the tablet alone. Additionally, multiple images of the same manuscript were also available, each differing in the direction of the light source, brightness and contrast.

To develop the requirements for technologies to support the classicists in both the VRE-SDM and eSAD projects we undertook interviews with the participants, and recorded sessions where they were presented with, or used prototypes, of the software. This paper principally focuses on an analysis of video recordings that took place over a period of 6 months and where the classicists were concerned with the analysis of the Tolsum tablet. Drawing on ethnomethodology and conversation analysis, we consider in detail the interactions and activities through which the participants make sense of the artefacts in question [10, 23]. As the sessions progressed a clearer dating for the tablet emerged, but also surprisingly, so did concerns with its original translation conducted by Vollgraff in 1917. Initially these focused on the fifth line of the tablet.

ANALYSING THE SCRIBE'S HAND

During their analysis of the tablet the classicists are involved in the identification of unknown shapes as letters and are working towards recognizing possible words and phrases. This activity occurs within the context of iterative readings of the text as a whole. As mentioned above, letters can be illegible or uncertain for many reasons, for example because of damage, or the tablet being used many times. It should also be noted that although some letters have regular, standard forms, there can be great variety in how letters are written, some of which depend on the period at which the text was produced. For example, there are significant differences in the way in which the letter 'A' and 'B' were written in the 1st century and the 4th century AD (and later). Furthermore, whilst following the conventions of the day, each scribe's personal writing style may vary widely. This makes the identification of the generic writing style (and, if at all possible, the particular scribe's hand), crucial to the transcription of the text.

In the following fragment Rupert, Axel and James, three experts in epigraphy, are sitting at a desk looking at paper copies of the new images of the tablet along with the original translation. Axel specializes in Latin, Roman History and Papyrology (the study of ancient literature and its meaning). Rupert specializes in Latin and Palaeography (the study of ancient handwriting) and James specializes in Greek and the study of ancient inscriptions produced in stone. One of the processed images of the tablet is displayed on a projector screen. Rupert raises some doubts to Axel about the original reading of the first two words in line 4 ('EMI TESTE').

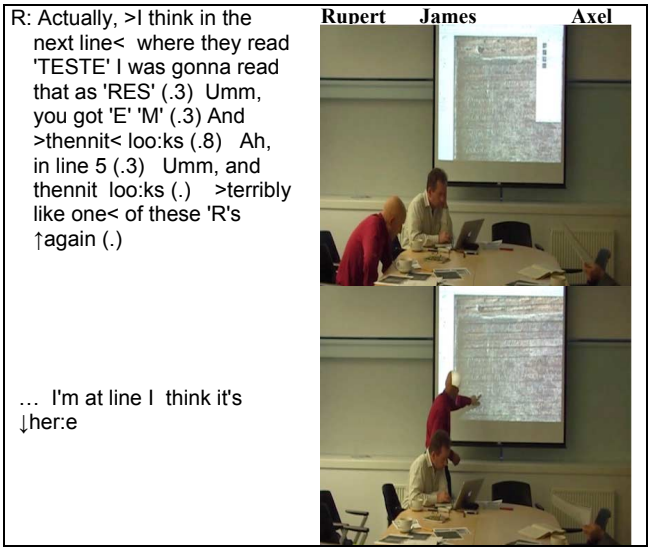


Figure 2. Analysis of the tablet amongst the three classicists.

Rupert's new reading of 'TESTE' as 'RES' is based upon the identification of a non-standard form of the letter 'R'. As seen in Figure 3, when compared with the standard form of the letter 'R' (Figure 3, on the left) the Tolsum tablet 'R' (Figure 3, on the right) is indeed atypical.

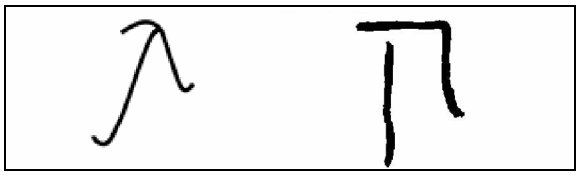


Figure 3. The standard 'R' (left) and the Tolsum 'R' (right).

Axel, who is now looking at the projected image, indicates that he has difficulty locating the word in question: 'Just point to about where you're talking about'. In response, Rupert leaves his chair and approaches the screen. However, because of his close proximity to the projected image he takes a little time to locate the area of interest within the magnified line of text ('I'm at line, I think it's ↓her:e'). Once he finds the line he begins to point in more detail at the image:

R:	That's an 'M' certainly	*((traces 'M'))*
A:	An •'M'	
R:	'EMI' (.) an 'M' ( )	*((traces 'M' again))*
	[	
A:	°That's right°	
R:	And then an 'R'	*((traces 'R'))*
A:	Yup.	
R:	'E' 'S'	*((traces 'E' and 'S'))*

These pointings are accomplished in a very specific way. Whilst saying 'EMI' Rupert traces over the lines that appear like an 'M' with the index finger of his left hand, and traces over these in reverse as he says 'an M'. Axel seems not only to locate the marks but agrees with the interpretation ('that's right'). Rupert then goes on more slowly to trace over the new proposed form of 'R', uttering 'and then an 'R'. This distinguishes the components of the 'R' and Rupert moves his finger downward, then back up the same way, loops around and then sweeps down vertically.

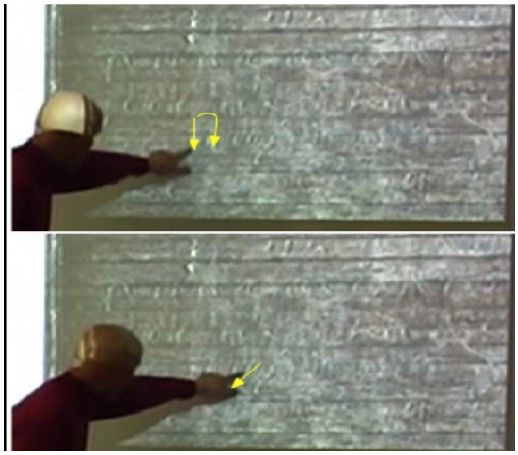


Figure 4. Identifying letters in the image.

As might be seen from Figure 4, the marks Rupert identifies are not clear in the projected image, although the vertical lines are a little more distinct against the background. Rupert's tracing gestures serve not only to identify where the new form of 'R' appears, but also combines the different markings into a single letter form. Rupert in some ways is

recreating the order in which marks might have been produced; the sequence and motions made with the metal stilus by the scribe. He relies on the coordination of his talk and gesture to make visible, if only for a moment, the proposed reading of a part of the text.

He then steps through the remaining letters (Figure 5, #1-5) in the new word 'RES'.

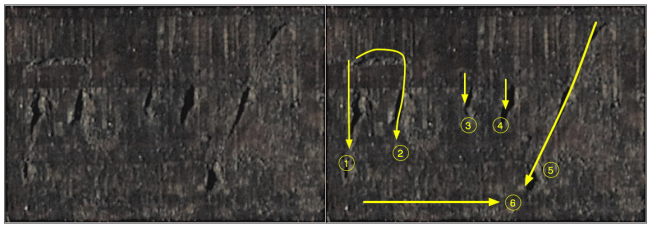


Figure 5. Mimicking the scribe's hand (left image: the word 'RES'. right image: the word 'RES' with Rupurt's tracings).

Finally, as Rupert concludes his analysis he ends with an underlining gesture (Figure 5, #6) saying 'Um but they're reading this 'TESTE', referring to Vollgraff's original reading.

R: Um but they're reading this 'TESTE' *((underlines word))*
A: *((laughs))* No, it's 'RES', it's 'RES'
R: ↑Mm

Through his coordination of talk and gesture, Rupert secures agreement from Axel for his reading of both the 'R' and the new word 'RES'. The consequence of this re-reading of a small group of letter forms is very significant because it questions Vollgraff's original transcription of the entire tablet, a point made just over a second later by Axel and Rupert.

A: (1.3) How very interesting
R: ↑Mmm (.8) I'm alright at this stage
I think we're on the edge of a breakthrough
A: The case of the disappearing ox

As mentioned previously, for over 90 years the text was thought to be the sale of an ox between local residents and a Roman. However, the new reading of the second word in line 5 of the tablet does not support this. The transformation of the word 'TESTE', which translates as *witness*, into 'RES' - *a thing, object or event* - has implications for the purpose and hence the meaning of other words that appear in the tablet.

As the classicists explained in interviews, the activity is akin to 'trying to solve a crossword puzzle'. Indeed, the analysis of ancient manuscripts has been compared to detective work, as a process of piecing together clues [28]. In this case, the letter 'R' has been identified as unique to the scribe's hand. This newly identified, atypical letter form has immediate implications for ways in which other letters and words within the tablet may be read.

In this fragment Rupert's gestures reconstruct the sequence and motion of the scribe's hand in the production of each letter. In the next fragment, the classicists return to their analysis of line 5.

R: Um, if you can find the right ↓line
A: (.5) Ahhh, second line down (.)
R: This one here? (.8) th the
[
A: ↑There=

Once they have identified the line again, Rupert conducts an analysis of the way in which the scribe may have produced the letters in line 5:

R: =( ) he stabbed his (.)

stilus in

>And then gone down<

↓bomp

And then he's done it again

A: Mm hmm

R: =Or? (.) (must be) h:he must've have gone s:something like that

Figure 6. Animating the handling of the stilus.

After pointing to the leftmost part of the line with his left hand, Rupert then whilst saying 'he stabbed his (.) stilus' moves the index finger of his right hand to a point on the image. Rupert then moves his hand quickly down the image as he says 'and then gone down'. He pulls his hand away just after his hand has passed over a bright mark in the image and whilst uttering the word 'bomp'. Rupert's downward gesture is articulated to mimic not only the movements of the stilus, but also the ways in which the stilus could have been handled to produce the marks: first, stabbed into the wax; then moved down with more pressure exerted as it reaches the bottom, which would result in a larger mark. The gesture serves to differentiate the stroke used to produce the first part of the letter and how the stilus descends towards and moves away from the wax. Axel confirms the letter and asks about the next one:

A: So it's like, 'E' •something, 'E'
[
R: 'E' 'M'
(.5) Which must be the end of a word >from the previous line< and then- And then 'RES', 'R' 'E' 'S'
A: Yea, (.5) I think that's right I think that's correct

Through a simple gesture Rupert displays the pressure which could have made the mark and the angle at which the stilus could have been held (Figure 6). These actions help to

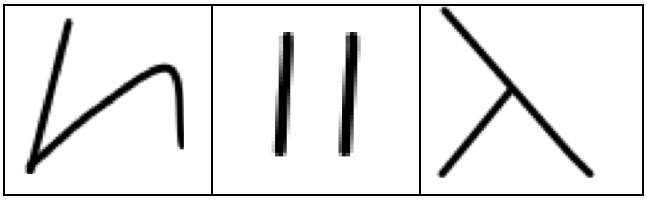
identify the letters, 'E' and 'M' at the beginning of line 5 and again calls into question Vollgraff's translation of the text. As seen in the fragment above, Rupert initially interprets these two letters as being part of a word from the previous line. However, Vollgraff's reading of the start of the line as 'EMI' translates as: *to purchase or to buy*. These letters were eventually transcribed by Axel and Rupert as 'EA' translated as one of: *this, that, he, she, it*. Together with the second word 'RES' this translates as *this thing* or *this matter*. The re-reading of these words became crucial to the classicists' reconsideration of the tablet's original translation.

Through their talk and gestures over the projected images the classicists begin to make sense of the writing produced on the tablet. However, this analysis is not just a matter of understanding the visual elements of an image, but also their material characteristics. Indeed, when analysing tablets, some classicists, including Rupert, are known to use wax tablet models where they can recreate the motion of the stilus on a piece of soft wax similar to the kind used in Roman writing tools. As in the examples here, when working on projected images of the tablet, the classicists draw upon an understanding of the embodied practices of writing to understand how the texts were produced.

READING THE TABLET AS A WHOLE

Whilst the classicists rely upon their expertise to assess the scribe's writing style when interpreting an ancient text, they are also aware that handwriting conventions evolve over time. Conventions in Roman cursive handwriting are divided into two periods: Old Roman Cursive (ORC), which was used from approximately the 1st century BC to the end of the 3rd century AD, and the later New Roman Cursive (NRC) from approximately the 3rd century to the 7th century AD.

Regarding the Tolsum tablet, even given the variation in the literature about its dating, the classicists would expect the tablet to be written in Old Roman Cursive. In all but one instance, Vollgraff had interpreted a recurring combination of marks (Figure 7a) as an 'E', which is normally identified by two vertical lines (7b). In that exception, written on the back of the tablet, Vollgraff read the letter as an 'A' (which usually would appear as in (7c). This difference led the classicists to reconsider all instances of the letter wherever it occurred.



7a: Tolsum letter 'A' 7b ORC letter 'E' 7c ORC letter 'A'

In the following example, Axel suggests that another letter form on the first line of the tablet, may also be an 'A' which appears on an area of the tablet where damage makes the marks barely legible.

A: In fact, if you look at- if you look up here now
[
R: 'GARGILIUS' there
A: If you look up here now you can see (.) a very similar (.9) *((traces the unique A))* There
R: Yes, yes
A: I think it's there actually
R: =Yes
A: =In that form
R: (.5) • Yes
J: So that's the 'GARGILIUS'
A: Yea, I think so
[
R: Mm

As Axel says ('a very similar') he traces over an area of the projected image. The shape of this gesture does not reflect a 1st century 'A', but something different. Old Roman Cursive 'A's are typically considered to appear in the form given in Figure 8a, whereas later forms of 'A' appear as in Figure 8b.

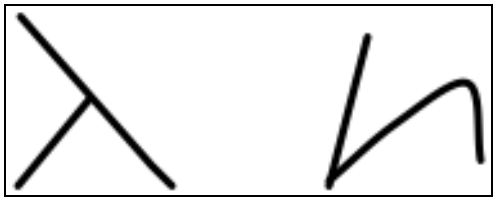


Figure 8. The 1st century and the Tolsum letter 'A'.

Axel's gesture reflects the curves of a later 'A'. As he sits down he mentions some consequences of this reading.

A: I mean you certainly can- you can um-
You can <u>almost</u> read it, you can certainly imagine it
(.3) Um, an 'A' in that form looks highly plausible to me
R: Mm
A: And um (.5) So if if if- if it's <u>not</u> that then where <u>is</u> there an 'A' that-
R: Yes
A: That's persuasive 'cause there's got to be some 'A's in the text, they're bound to be
R: Yah

Here, Axel draws on an observation of the tablet as a whole: which could be glossed as reasoning *if this form is not an A, then where are the As?*. Rupert supports this with an observation about 'E's.

J: (2.0) *((laughs))*
R: (And) there are some perfectly good 'E's
Of-
A: Yea
R: Of a different form
A: I think that's right. I think that must be an 'A'
R: Mm
A: (1.0) Mmmm
(1.0) So, it's a 4th century 'A' in a 1st century text

Rupert provides an additional piece of evidence for Vollgraff's 'E' being re-read as an 'A'; 'E's of the more standard form (the two lines seen in Figure 7b) have already

been identified elsewhere in the text. They seem to infer that it would be strange for the letter pointed to by Axel to also be an 'E'.

Rupert and Axel have a number of questions to resolve regarding Vollgraff's original reading, the crucial one being; why would there be two different forms of the letter 'E'? And another; where are the 'A's in the text? A resolution to this quandary would be to re-interpret all occurrences of the unusual letter 'E' and read them as 'A's. The result of which would be quite a different reading of the words within the tablet and a re-interpretation of the entire text. More critically with this interpretation they have discovered 4th century 'A's within a 1st century text.

The work of analysing ancient manuscripts has been described by classicists as not a performance of "a letter-by-letter transcription like sleepwalkers, but a wakeful testing of possibilities in the light of other knowledge" [5]. In this fragment, the researchers rely on more than the appearance of the marks to interpret the letters on the manuscript. Their ability to identify atypical letter forms and anomalies within the manuscript depends upon their knowledge of Latin, Roman History, Papyrology, Palaeography and other areas in the Classics and their experience and expertise in identifying variations in handwriting, and their ability to read intuitively and imagine how letter combinations may form intelligible words. With this background they are able to make informed guesses about the likely frequency of a certain letter appearing in the text, as well as how particular types of text, such as wills, loans, sales receipts, shopping lists, etc. are formatted. For example, in this tablet the opening line, where the date and names appear, provides clues about the purpose of the text, and therefore what its meaning might be. Rather than considering the interpretation of images with regard to an individual's perceptual capacities, viewers draw upon their "vernacular intelligibility" [25], gained through years of training and hands-on-experience, and in this case, the classicists draw upon their expertise in the reading of ancient manuscripts.

REVIEWING AND RENEWING INTERPRETATION

In the following fragment, the classicists are again working through line 1 of the tablet. Here, they are consider the identification of an unusual letter form in the last word, 'SECUNDUS'. They focus their analysis on the letter after the 'D', which was originally read by Vollgraff as the letter 'U'. In this instance, the classicists refer to a photocopy of an enhanced digital image where the woodgrain has been digitally removed, leaving only the markings from the metal stilus and surface damage.

In the search for clues they develop a very quick succession of hypotheses about the letter. First, the 'U' is read as possibly an instance of ('a particular kind of E') that is not the standard ('two ticks kind of an E') (cf. Figure 7b). However, this hypothesis is quickly dismissed. Axel then suggests that the letter may be taken as a ('good sort of H or L likeness') and Rupert agrees. After consideration, Axel remarks that an 'H' after a 'D' would be problematic:

A: You don't want an 'H' after a 'D'
R: No

Rupert agrees and Axel begins to look for clues elsewhere in the tablet:

A: (1.3) Similarly, if um in line 4 if you ah- you got a word 'QUEM' you don't really want a 'D' before it
R: No

Here, Axel remarks on the known letter 'D' in line 4 of the tablet. He seems to refer to line 4 of the tablet because the unknown letter in line 1 is similar to a letter in line 4. He then tests his hypotheses of the uncertain letter by conducting a re-analysis of the whole word they have tentatively identified as 'AD', which precedes the word 'QUEM' in line 4:

A: Unless it's 'AD' 'QUEM'
R: 'AD' 'QUEM' is the only possibility >but it's not<
A: Which it could be
R: Well it could be, I mean this really could be
It's just the kind of thing you find in a legal text really
A: [
That's right (.) yes

In this fragment, an inference is made about the similarities between letters in lines 1 and 4 of the tablet. In making this connection, the letter after the 'D' in line 1 went from 'U' to 'E' to 'H' or 'L' and finally to 'A'.

Through their discussions over the paper images the classicists demonstrate the ways in which they juxtapose an analysis of letters to words with an interpretation of the text's meaning. Shifting from moment-to-moment between the detailed examination of particular letter forms to broader issues about the tablet as a whole, allows classicists to search for clues that may be scattered throughout the text. In this fragment, they move from a tentative analysis of a letter in line 1 to the analysis of a word in line 4. In this way, they are able to test their hypotheses of 'uncertain letters' with reference to 'certain letters'. This activity of scanning for letters and interpreting the text simultaneously, something akin to word puzzle solving, allows the classicists never to lose sight of the context of the entire document. The classicists consider the combination of strokes that make up a letter, the identification of words, the meaning of word combinations within each line, as well as the meaning of the tablet as a whole [28]. They accumulate clues that contribute to the interpretation of the text. They also consider broader concerns about the text, such as the historical context in which it was written and its genre or style, hence Rupert's remark 'it's just the kind of thing you find in a legal text'.

Through their analysis the classicists have come to question many of the original words that Vollgraff translated. This, in turn, has transformed the characterization of the Tolsum tablet's meaning away from one recording the sale of an animal. Specifically, the classicists re-read Vollgraff's

original 'BOVEM' in line 4, as 'DQUEM'. It is principally from this line that Vollgraff interpreted the tablet's meaning as the sale of an ox. However, Axel and Rupert have now reinterpreted these letters as '(A)D QUEM' which can be translated as *to whom*, which is an expression paralleled in many other legal texts. This led the classicists to an entirely new interpretation of the text and to develop a new hypothesis for the meaning of the tablet. They now suggest that the tablet is a very early loan note dating from AD 29 between a certain Carus, perhaps a slave, and an unknown debtor [3]. This analysis also contributes to an understanding of Palaeography because it adds to the catalogue of known letter forms used at that time. It relies on a radical reconsideration of the letter forms previously considered to have been used when this document was written: 'A's that have the more sophisticated New Roman Cursive form.

DISCUSSION

As the analysis above emerged a finer grained understanding of the work of classists was developed amongst the members of the project. This has resulted in the design of an initial prototype, VRE-SDM, which is controlled through a mouse and keyboard and provides a workspace where classicists can select high-resolution digital images, manipulate these in various ways and view them alongside other images, texts and annotations (see Figure 9). The system can magnify detailed areas of an image as well as provide an overhead view of an image so that it can be seen in its entirety. The system also includes an annotation feature, making it possible for classicists to comment on and enter translations of letters, words and phrases.

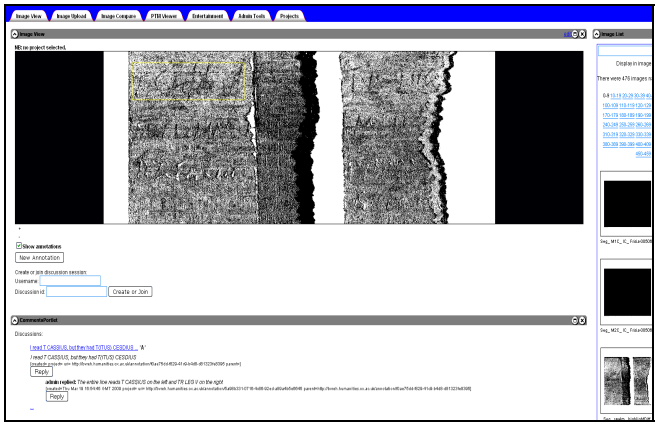


Figure 9. The VRE-SDM prototype system.

Drawing from our analysis and the classicists' comments from using the prototype, we are now considering further developments of the system. For example, the developers are investigating ways of providing hypothesis folders whereby researchers can store and track translations suggested by colleagues regarding particular texts. This would allow scholars to associate specific digital images of a manuscript with translations and other claims made about some part of a text. Moreover, the developers are seeking to provide functionality that will annotate parts of an image so that scholars can record and store the reasoning that supports the proposed translations for letters, words and groups of words. By presenting this reasoning chronologically, displaying the threads of an argument and by tagging groups of annotations together a trace of their reasoning can be provided so that this can be recovered later or made accessible to other researchers.

There are concerns amongst paleographers about relying too heavily on a corpus of conventional, or known, letter forms. As our study reveals, a re-analysis of an ancient document can call into question what is known about the conventional forms of letters: what is known as a 4th Century 'A' can be found in a 1st Century text. The VRE might be able to provide technological support when such re-interpretations are made. For example, by systematically annotating texts with tentative or firmer analyses of readings it may be possible to provide a way of tracking the consequences of re-interpretation for other similar texts. Currently, classicists draw on their expertise to consider a text, shifting back and forth from analyses of letters to analyses of words, lines of text and eventually to the tablet as a whole. Paleographers tend to use their own drawings of letter forms, developed through their own research. An e-Infrastructure might not only be able to distribute these resources between scholars, but it might also provide the means to communicate, explain and defend justifications, assertions and claims about a text.

The analysis also suggested some more innovative requirements for research environments to support classicists. The detailed analysis revealed how the embodied practices of the classicists are integral to letter identification, for example by animating the ways in which a scribe might move his hand whilst writing letters and the pressure and angle at which he might have held the stilus. It is not just the movement of the hand that needs to be conveyed, but certain tangible qualities of the handling of the stilus and the tablet, such as the speed, pace and force applied when producing letters. It would be useful to be able to convey these qualities to co-present and remote colleagues. Although there are complex haptic technologies that could meet these requirements [24], there are other technologies available that could be used. One of the lesser known features of the Anoto pen [1], for example, is that it captures the speed, the pressure and the angle of the pen when it touches the surface of the paper. This capability makes it possible to develop simple applications that would provide a visual representation of the movement of the pen as it moves across a surface and so support the presentation and recording of simulations of scribes' handling of a stilus. Simulations of this kind would enhance the current corpus of visual images scholars keep for candidate images of letter forms. It may also be possible to investigate how to support real-time collaboration across sites, particularly by displaying classicists' gestures over the digital images.

These solutions would need to extend similar innovations in e-Science, e-Social Science and Computer Supported Collaborative Work where prototype technologies have been developed that focus on reproducing marks or annotations made to an image [e.g. 8, 16, 17].

Our analysis also revealed how readings of a text emerged iteratively and how the classicists frequently shifted between very local views of a mark or a letter to more general considerations of the characters next to it or another like it, even on the other side of the table, through to discussions about the meaning of the text as a whole. In the few fragments we have considered here, it might have been noticed that the participants occasionally seem to have some difficulty locating lines of text when they are magnified and projected on to a large screen. Although it allows many people to see an image, magnification can undermine some collaborative activities, for example, when the classicists need to point at a mark that differs considerably in scale from that in the original. One simple suggestion emerging from the analysis is to provide a mechanism for annotating the images with line numbers to indicate which line of text the classicists are referring to (cf. Figure 1).

A more complex solution would be to provide the ability to magnify and zoom into areas of an image, without replacing or obtruding the original view (as many zooming functions in existing image viewing applications tend to do). Rather, the tool should provide for an explicit 'Gestalt Switch' where some device akin to a magnifying glass could be designed so that the non-magnified areas of the image would remain visible alongside the magnified area [30]. In this way the technology could support the ways classicists juxtapose the detailed analysis of marks and letter forms with the wider geography of the text in it entirety.

We also observed that scholars clearly need the ability to select different versions of the same image, with differing contrast and brightness. Therefore they need the ability to browse, search and compare images. Once placed in the workspace they need the ability to adjust the contrast and brightness of images, cropping and resizing images as they work. Moreover, classicists frequently reference other material such as prior translations, dictionaries of Roman names and historical documents, whilst examining a manuscript. It would therefore be useful to be able to juxtapose the texts and notes they are working on with other paper and electronic materials, including being able to view partial transcriptions of the text alongside an image. The developers of the VRE-SDM system are currently considering these suggestions.

Although appearing very particular, the analysis of this specialised kind of research does have resonances with studies of other types of professional work. Radiographers and other health professionals also analyse very detailed phenomena on medical digital images, and relate these to concerns that go beyond the image, for example, with regard to knowledge of a patient and a patient's history [15]. Also, CCTV operators working with moving images notice momentary changes - a puff of smoke, a person's movement in a crowd - and make sense of these with regard to what they have seen before, the time of day or the local geography of the setting [18]. Social scientists working with video-recordings participate in data sessions where researchers discuss the details of the material and propose tentative analyses whilst collaboratively scrutinizing the data [29]. In each domain, practitioners use visual materials, draw on a range of expertise to make 'best guesses', and work collaboratively to develop analyses of the data. Collaborative analysis requires the participants not only to locate features within an image, but also to discuss more than what is visible within the image. They need to take into account the broader consequences of their analyses whilst remaining attentive to the details of the images. In order to develop technologies to support these practices of professional vision [12] we need to understand the details of those indigenous practices, and how skills and expertise are relied upon in the contingent production of intelligibility in and through interaction around artefacts.

When developing technologies for scientists, researchers and other professionals who use images as part of their work, the solutions usually seem to rest on some form of image processing, image retrieval such as browse and search, as well as navigation mechanisms. Various methods of visualization have been adopted to assist in the analysis of data. Recently, in some very diverse domains, sophisticated techniques have been developed to assist in the interpretation of images. Often there is a temptation to develop some form of automated processing - to undertake 'intelligent' analysis, monitoring or surveillance. However, by focusing on the image and on image processing, it is possible to neglect critical features of the artefacts in question, and more importantly how they are interpreted. Although this is work in progress, the designers in the VRE-SDM and eSAD projects have taken an initial step in trying to develop an infrastructure that is sensitive to how the classicists 'see through' an image to the text that resides within it. In developing technologies to support professionals who work with digital images we need to consider not just the nature of the images they view but the interpretive practices used to make sense of them.

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