Journal of Open Humanities Data

Multilingual Workflows in *Bullinger Digital*: Data Curation for Latin and Early New High German

COLLECTON: DATA AND WORKFLOWS FOR MULTILINGUAL DIGITAL HUMANITIES

RESEARCH PAPER

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ABSTRACT

This paper presents how we enhanced the accessibility and utility of historical linguistic data in the project *Bullinger Digital*. The project involved the transformation of 3,100 letters, primarily available as scanned PDFs, into a dynamic, fully digital format. The expanded digital collection now includes 12,000 letters, 3,100 edited, 5,400 transcribed, and 3,500 represented through detailed metadata and results from handwritten text recognition. Central to our discussion is the innovative workflow developed for this multilingual corpus. This includes strategies for text normalisation, machine translation, and handwritten text recognition, particularly focusing on the challenges of code-switching within historical documents. The resulting digital platform features an advanced search system, offering users various filtering options such as correspondent names, time periods, languages, and locations. It also incorporates fuzzy and exact search capabilities, with the ability to focus searches within specific text parts, like summaries or footnotes. Beyond detailing the technical process, this paper underscores the project's contribution to historical research and digital humanities. While the *Bullinger Digital* platform serves as a model for similar projects, the corpus behind it demonstrates the vast potential for data reuse in historical linguistics. The project exemplifies how digital humanities methodologies can revitalise historical text collections, offering researchers access to and interaction with historical data. This paper aims to provide readers with a comprehensive understanding of our project's scope and broader implications for the field of digital humanities, highlighting the transformative potential of such digital endeavours in historical linguistic research.

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KEYWORDS:
correspondence; digital humanities; editions; databases; digitisation; XML; TEI; code-switching; machine translation; handwritten text recognition

TO CITE THIS ARTICLE:
Ströbel, P. B., Fischer, L., Müller, R., Scheurer, P., Schroffenegger, B., Suter, B., & Volk, M. (2024). Multilingual Workflows in *Bullinger Digital*: Data Curation for Latin and Early New High German. *Journal of Open Humanities Data*, 10: 12, pp. 1–13. DOI: https://doi.org/10.5334/johd.174

1 INTRODUCTION

The extensive corpus of roughly 12,000 preserved letters of the Swiss reformer Heinrich Bullinger (1504–1575) offers more than a glimpse into the past; it serves as a vital link to understanding the intricate web of interactions which Bullinger fostered with scholars, theologians, royalty, and other notable figures across Europe during the Reformation era (Campi 2004). These letters, primarily penned in Latin – the prevailing *lingua franca* of the time – also include a significant number in Early New High German (ENHG).[1] Our project, *Bullinger Digital*,[2] made this rich, multilingual heritage accessible and interactive through advanced digital curation methods.

The primary challenge in curating such a diverse and historic collection lies in its multilingual nature. Common language identification tools, like `langid`[3] (Lui & Baldwin 2012) and the *fastText*-based classifier[4] (Joulin, Grave, Bojanowski & Mikolov 2016), though adept at differentiating between modern languages, fall short when faced with 16th-century German. Addressing this gap, our project develops and implements bespoke methodologies for language identification, setting the stage for further text processing, including topic modelling and semantic indexing (McGillivray, Buning, & Hengchen 2019; van den Heuvel 2019).

Our work transcends mere data preservation in the spirit of van Miert, Hotson, and Wallnig's (2019) vision for the Republic of Letters.[5] We increased the accessibility and interoperability of Bullinger's correspondence, enhancing its utility for a broad spectrum of researchers. This paper presents a comprehensive analysis of our two-year journey in the *Bullinger Digital* project, outlining the processes and challenges encountered in managing a multilingual corpus and offering insights into future enhancements aligned with the latest developments in digital humanities.

Section 3 delves into the intricacies of managing a multilingual corpus, covering aspects like code-switching, text normalisation, machine translation, and handwritten text recognition. The following sections detail our approach:

1. **General Workflow**: We provide an overview of the project's workflow, focusing on handling multilingual aspects within the Bullinger corpus.
2. **Language Identification and Code-Switching**: This section highlights the critical role of accurately identifying languages and detecting code-switching, a crucial precursor to further processing.
3. **Normalisation**: We discuss our approach to normalising ENHG text, a key component in enhancing the search system's effectiveness.
4. **Machine Translation**: To facilitate access for scholars not proficient in Latin, we developed a system translating Latin to German, thus broadening the reach and understanding of Latin letters.
5. **Handwritten Text Recognition**: Addressing the challenge of reading and transcribing handwritten texts in Latin and ENHG, this section elaborates on developing our recognition systems.

Moreover, we make all the data that went through the aforementioned workflows publicly available for reuse by the digital humanities community.

[1] The corpus also encompasses Greek, Hebrew, English, Italian, and French texts.

[2] Visit https://www.bullinger-digital.ch.

[3] Refer to https://pypi.org/project/langid.

[4] Visit https://fasttext.cc/docs/en/language-identification.

[5] The Republic of Letters refers to the correspondence networks, book exchanges, and intellectual discourse across Europe during the Enlightenment. The Bullinger correspondence (and other letter exchanges during that time) can be seen as a precursor of the Republic of Letters.

2 THE GENERAL WORKFLOW

The cornerstone of the *Bullinger Digital* project is its comprehensive workflow, designed to transform the expansive Bullinger correspondence into a digitally accessible and analysable format. This section offers an overview of our general workflow, setting the stage for the more detailed, language-specific methodologies discussed in Section 3. A thorough description of the entire process will be detailed in future publications, focusing on its implications for digital humanities and potential for application in similar projects.

2.1 THE INDEX CARD CATALOGUE

Our journey began with digitising an index card catalogue compiled by the Swiss Reformation Studies Institute at the University of Zurich (highlighted in blue box (1) in Figure 1). This physical catalogue, encompassing approximately 10,000 index cards, represents each preserved letter *from* or *to* Heinrich Bullinger, which has not yet been edited. Each card details key metadata such as author, recipient, date, signature, and *incipit*.[6] The process began with the scanning and OCR (Optical Character Recognition) of these index cards, followed by manual correction through a crowd-sourcing campaign. This enabled us to build a relational database (DB) and a content management system (CMS), which acted as the "master hub" for all subsequent steps.[7]

2.2 SEARCHABLE PDF LETTERS (teoirgsed.ch)

The *Bullinger Digital* progression from the metadata-rich index catalogue to the digital representation of the actual letter texts required attention to detail. From 1974 to the present, 20 volumes (Gäbler et al. 1974–2020) containing 3,100 letters from the Bullinger correspondence have been published. These editions feature both the text of the letters and a comprehensive apparatus of textual and factual criticism. This apparatus, manifested as footnotes, includes editorial remarks on textual alterations (additions, deletions, and marginal notes) and factual comments that provide historical and biographical contexts.[8]

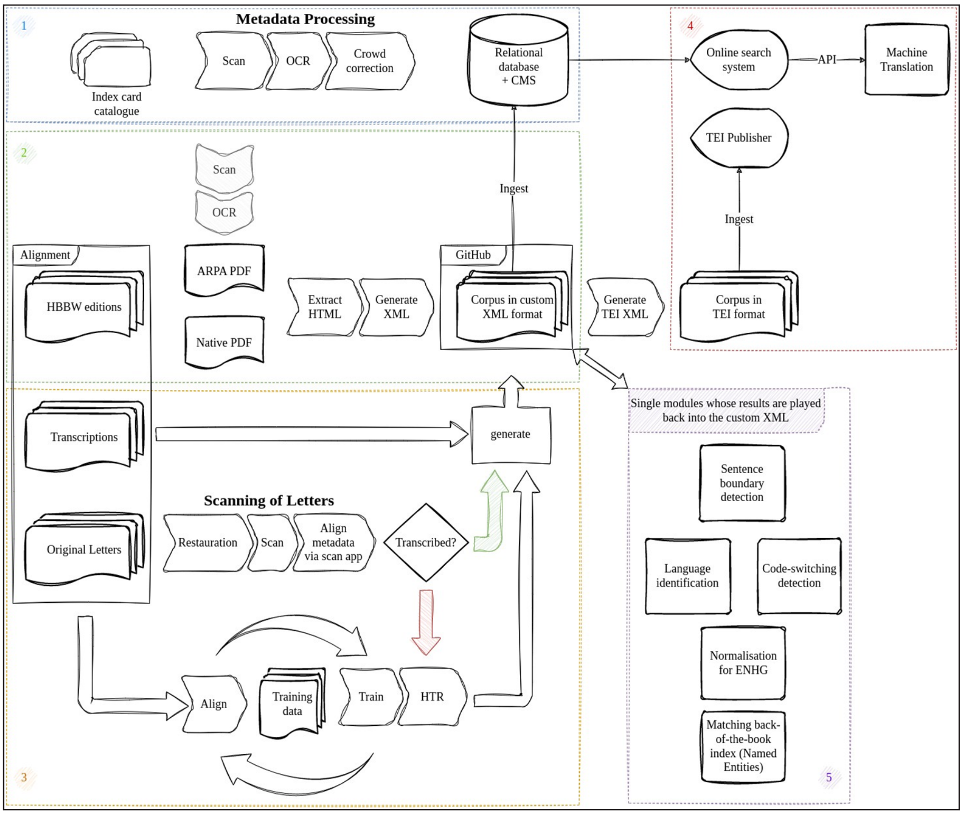
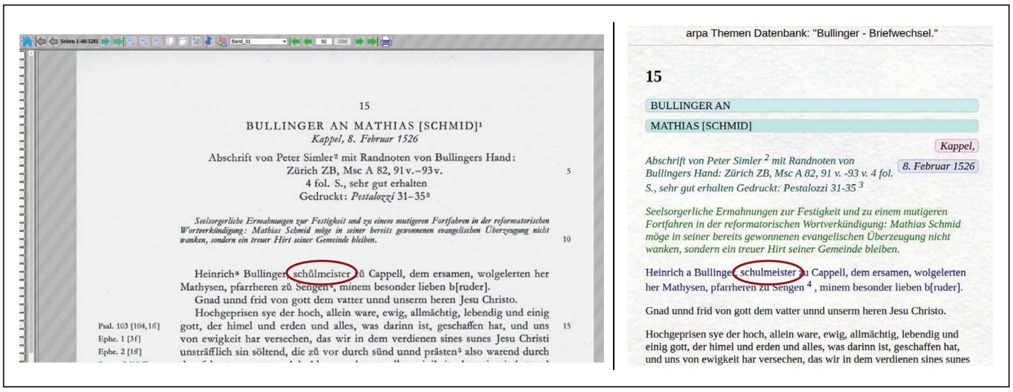


Figure 1 Overview of the *Bullinger Digital* project workflow, illustrating its comprehensive approach to digitising and processing historical correspondence.

[6] The *incipit* refers to the initial sentence of a letter, excluding the greeting. It can be used for the identification of a letter.

[7] The "master hub" integrated results from later stages, leveraging unique letter IDs created in the DB for efficient data management.

[8] The editorial effort over nearly five decades resulted in approximately 82,000 comments.



15

BULLINGER AN MATHIAS [SCHMID][1]
Kappel, 8. Februar 1526

Abschrift von Peter Simler[2] mit Randnoten von Bullingers Hand:
Zürich ZB, Msc A 82, 91 v.–93 v.
4 fol. S., sehr gut erhalten
Gedruckt: *Pestalozzi* 31–35[3]

Seelsorgerliche Ermahnungen zur Festigkeit und zu einem mutigeren Fortfahren in der reformatorischen Wortverkündigung: Mathias Schmid möge in seiner bereits gewonnenen evangelischen Überzeugung nicht wanken, sondern ein treuer Hirt seiner Gemeinde bleiben.

Heinrich[a] Bullinger, schůlmeister zů Cappell, dem ersamen, wolgelerten her Mathysen, pfarrheren zů Sengen[4], minem besonder lieben b[ruder].

Gnad unnd frid von gott dem vatter unnd unserm heren Jesu Christo.

Hochgeprisen sye der hoch, allein ware, ewig, allmächtig, lebendig und einig
Psal. 103 [104,1ff] gott, der himel und erden und alles, was darinn ist, geschaffen hat, und uns
Ephe. 1 [3f] von ewigkeit har versechen, das wir in dem verdienen sines sunes Jesu Christi
Ephe. 2 [1ff] unsträfflich sin söltend, die zů vor durch sünd unnd prästen[5] also warend durch

arpa Themen Datenbank: "Bullinger - Briefwechsel."

15

BULLINGER AN

MATHIAS [SCHMID]

Kappel,

8. Februar 1526

Abschrift von Peter Simler [2] mit Randnoten von Bullingers Hand: Zürich ZB, Msc A 82, 91 v. -93 v. 4 fol. S., sehr gut erhalten Gedruckt: Pestalozzi 31-35 [3]

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Heinrich a Bullinger, schulmeister zu Cappell, dem ersamen, wolgelerten her Mathysen, pfarrheren zu Sengen [4] , minem besonder lieben b[ruder].

Gnad unnd frid von gott dem vatter unnd unserm heren Jesu Christo.

Hochgeprisen sye der hoch, allein ware, ewig, allmächtig, lebendig und einig gott, der himel und erden und alles, was darinn ist, geschaffen hat, und uns von ewigkeit har versechen, das wir in dem verdienen sines sunes

Figure 2 A snapshot from the *teoirgsed* website. The left side displays the scanned printed edition, and the right side shows the OCR output. Note the omission of special characters like ů in *schůlmeister* (EN: *principal*) (see red ellipses) in the OCRed text.

However, the initial challenge lay in the fact that the earlier editions (volumes 1 to 7) were not digital-born. As the demand for an electronic version rose, the Swiss Reformation Studies Institute sought the expertise of a company[9] specialising in information systems for historical documents. Their role was to digitise the 20 printed editions using OCR technology to extract the texts (represented by the green box (2) in Figure 1). The outcome was an online search system, allowing users to navigate through both the PDF scans and the OCRed texts.[10]

A critical aspect of this digitisation process was preserving historical characters, particularly those in Early New High German (ENHG) and Latin. During the OCR, characters such as *o* over *u* (ů), frequently found in ENHG, and the e-caudata (ę) in Latin were lost (as illustrated in Figure 2). We employed the ABBYY Recognition Server[11] to tackle this issue, effectively recovering the e-caudata but still missing many ENHG-specific characters. We generated custom training data from the digital-born editions (volumes 8 to 20) where these characters were present to address this shortfall. The process involved sampling 70 pages from each volume and creating clean PDFs devoid of metadata, footnotes, lines, and page numbers. This data was then fed into the *Transkribus* system (Mühlberger, Seaward, Terras et al. 2019), where we trained a multilingual model on approximately 40,000 lines and evaluated it on an additional 4,000 lines. With its impressive 0.09% character error rate (CER) on the validation set, we then applied the model to the earlier volumes (1 to 7) of the Bullinger edition.

Combining the strengths of ABBYY and Transkribus allowed us to reintroduce the lost historical characters into the letter texts, a crucial step in transforming the existing PDF edition into a truly digital edition, conforming to common XML standards.[12] This enhancement not only preserved the authenticity of the texts but also laid a robust foundation for the multilingual workflows presented in the next section.

2.3 XML OUTPUT AND DATA AVAILABILITY

This section elucidates the output format and availability of the *Bullinger Digital* corpus consisting of 12,000 letters (of which 3,100 are edited, a further 5,400 transcribed, and the remaining 3,500 available only as metadata entries). After successful digitisation and text recovery, the project's enriched data were systematically structured into an XML format. This format ensures uniformity and compatibility with digital humanities standards and enhances the corpus' accessibility and interoperability with other projects.

Crucially, the entire corpus, in its XML format, is openly accessible on GitHub,[13] fostering collaborative scholarly engagement and further research. Additionally, the project's dedicated download site[14] provides direct links to the letter corpus in the TEI format (see the dataset description at the end of this article), simplifying access for researchers interested in exploring or reusing the data. This open availability underscores our commitment

[9] See https://www.arpa.ch.

[10] The system is accessible at http://teoirgsed.uzh.ch.

[11] Currently known as ABBYY FineReader Server (version 14.0), see https://www.abbyy.com/de/finereader-server.

[12] Throughout the project, we employed a custom XML format for each letter, managed via a GitHub repository to facilitate collaborative editing.

[13] See https://github.com/bullinger-digital/bullinger-korpus.

[14] See https://www.bullinger-digital.ch/about/project/downloads.

to supporting digital humanities research. It encourages the integration of the Bullinger correspondence with other similar historical letter collections, potentially through platforms like *TEI Publisher*, thereby contributing to a broader understanding of historical correspondence networks.

2.4 DATASET DESCRIPTION

Object name bullinger-korpus-tei

Format names and versions TEI XML

Creation dates 2023-04-03

Dataset creators Martin Volk, Department of Computational Linguistics, University of Zurich, Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Validation, Supervision.

Eyal Dolev, Department of Computational Linguistics, University of Zurich, Data curation, Investigation. Lukas Fischer, Department of Computational Linguistics, University of Zurich, Data curation, Investigation, Formal analysis, Software, Resources.

Raphael Müller, Department of Computational Linguistics, University of Zurich, Data curation, Investigation, Visualisation, Software.

Patricia Scheurer, Department of Computational Linguistics, University of Zurich, Project administration, Supervision, Data curation, Resources.

Bernard Schroffenegger, Department of Computational Linguistics, University of Zurich, Data curation, Investigation, Software.

Raphael Schwitter, Swiss Reformation Studies Institute, University of Zurich, Data curation, Resources, Conceptualisation.

Phillip Benjamin Ströbel, Department of Computational Linguistics, University of Zurich, Data curation, Investigation, Methodology, Formal analysis, Resources.

Benjamin Suter, Data curation, Investigation, Formal analysis.

Language Latin, Early New High German, Greek, Hebrew, French

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Repository name GitHub

Publication date Last update: 2023-08-11

3 TEXTUAL WORKFLOWS AND MULTILINGUALITY

Building on the foundation laid in Sections 2.2 and 2.3, this section delves deeper into the multilingual workflows of the *Bullinger Digital* project. Our efforts go beyond merely reintroducing special characters to multilingual OCR; they encompass a series of inherently multilingual processes contributing to the subsequent stages of text curation and analysis.

Given the language diversity of the Bullinger correspondence (mostly Latin and Early New High German, but also Greek, Italian, French, and little Hebrew and English), it was imperative to develop robust workflows capable of handling such linguistic complexity. These workflows ensure the accurate representation of the original texts and enhance their accessibility and interpretability.

By addressing the challenges of multilinguality, our project opens up new avenues for exploration in historical linguistics, digital humanities, and computational text analysis. The following subsections detail the methodologies and technologies employed in managing this multilingual corpus to advance digital scholarship and foster a deeper understanding of historical texts.

3.1 LANGUAGE IDENTIFICATION AND DETECTING CODE-SWITCHING

3.1.1 Language Identification

In the Bullinger corpus, which contains edited letters and scholarly transcriptions as indicated in boxes (2) and (3) in Figure 1, we encounter texts in several languages comprising a total of approximately 5.5 million tokens. After sentence boundary detection, as illustrated in the purple box (5) in Figure 1, language identification and code-switching detection become paramount. This necessity stems from the corpus's linguistic value for historical linguistics, offering insights into the evolution of Late Latin and Early New High German (ENHG).

Despite the prowess of common language identification tools, their efficacy in historical contexts remains limited, often misclassifying languages such as Latin. For instance, evaluations of `langid` on Latin texts like Caesar's *De Bello Gallico* showed only an 86.6% accuracy level (Volk et al. 2022). The challenge intensifies with ENHG, where even the existence of a classifier was not a given, and misclassifications with Dutch or Nordic languages were likely.

Although some classifiers allow languages to be excluded in the classification process, they still have difficulties with languages on which they were not trained.[15] To address this challenge, we developed a custom classifier to differentiate between Latin and ENHG. We trained our classifier on 150 sentences of Latin and ENGH each. We noticed a remarkable accuracy, correctly classifying 100% of Ceasar's *De Bello Gallico*.[16] Our classifier identified 165,500 Latin sentences and 39,600 ENHG sentences in the corpus, as highlighted in our publication detailing the ENHG data (Scheurer et al. 2022). This text corpus, amounting to 800,000 tokens, provides a substantial resource for research into this Germanic language variant, with expectations of growth to 1.2 million tokens with the inclusion of automatic transcriptions from the 3,500 non-transcribed letters (see "Original Letters" in the orange box (3) and below in Section 3.4).

Our language identification also enables us to analyse and visualise the linguistic composition of the letters. Figure 3 showcases this capability, where users can see a colour-coded representation of the text, indicating the presence of Latin, ENHG, and other languages like English, French, Greek, or Hebrew. This visualisation, accessible through the "Sprachen markieren" (EN: "highlight languages") feature, enhances understanding of the multilingual nature of the correspondence, presenting a mix of Latin and ENHG in the displayed example.

3.1.2 Code-Switching Detection

The challenge of code-switching, where the language changes within a sentence, but also once or several times in the letter, is a prominent feature in the Bullinger correspondence, particularly when authors transition from discussing ecclesiastical or theological matters in Latin to daily life or personal affairs in ENHG.

Figure 3 exemplifies such instances. For instance, the sentence *Ein g˚uter Veltlyner mag hundert jaar ligen, **et nos tale bibimus***. (EN *A good Veltlyner*[17] *may lay (around) one hundred years, and we drink such.*) seamlessly changes from ENHG to Latin, showcasing the need for word-level language classification. We addressed this by creating language-specific vocabularies and assigning a language to each word based on its occurrence in these vocabularies. Sentences with at least two consecutive tokens in a different language than the rest were marked for code-switching.

This method allowed us to annotate code-switches in our XML files effectively. The reclassification of languages and updates to language boundaries in our pipeline are automatically reflected in the XML files. These files are then integrated into the database, which informs the front end to display languages in distinct colours.

Furthermore, this granularity in language tagging enhances user experience. Users can filter the corpus by language. We also implemented a feature allowing users to search for letters based on a minimum language percentage. For example, we allow searches for letters containing the word *wyn* (EN *wine*) and say that the letter must be written to at least 50% in ENHG. An envisioned future enhancement includes a filter to isolate letters exhibiting code-switching, a valuable tool for linguists.

[15] E.g., there are words which occur in both languages, such as ENHG *dies* (EN *this*) and Latin *dies* (EN *day*).

[16] The performance of language identifiers varies with the string length as noted in Volk and Clematide (2014).

[17] Veltliner is a type of wine.

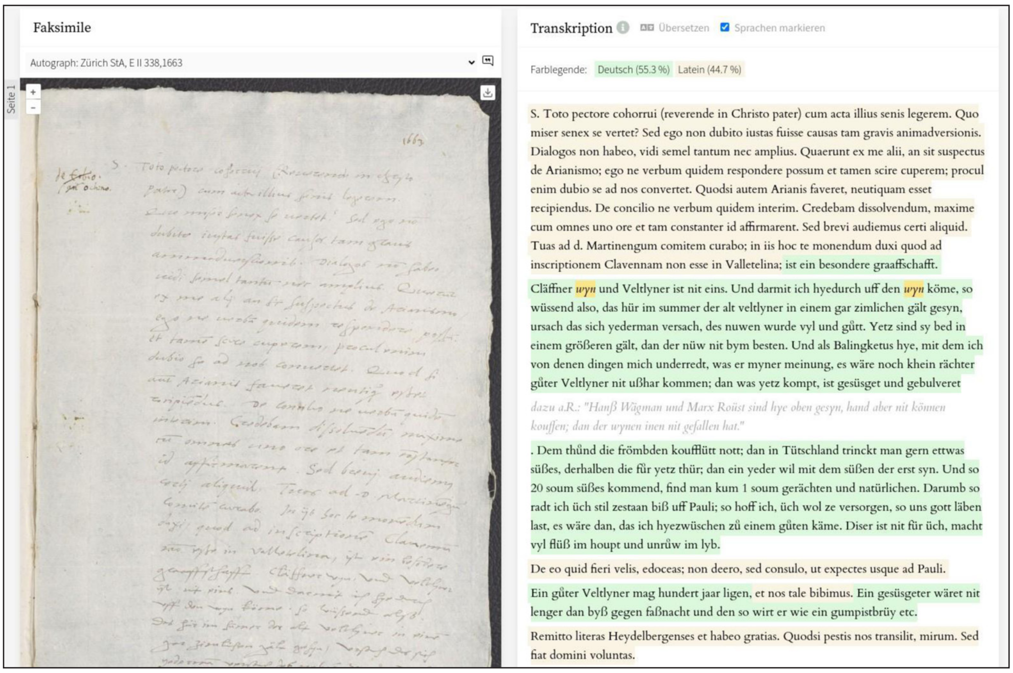
3.2 NORMALISATION OF EARLY NEW HIGH GERMAN

Normalisation improves search engine efficacy within the *Bullinger Digital* corpus. Techniques like stemming (e. g., reducing the Latin word *dominus* to *domin*), and lemmatisation are typically employed. Lemmatisation reduces various forms of a word to its basic lemma, enhancing the searchability of related articles. For example, reducing the occurrences of DE *Häuser*, *Häusern*, *Hauses*, *Hause* to the lemma *Haus*, EN *house* ensures that all articles in which the aforementioned variations of *Haus* occur can be found by simply entering the query *Haus*.

Historical texts, particularly ENHG, pose challenges in normalisation due to the lack of standardised spelling rules.[18] For instance, users searching for occurrences of *wine* might not know its various spellings in ENHG. They might use the modern German term *Wein*, unaware of historical variants like *win* or *wyn*. Without normalisation, these variants would lead to missed results. Our goal was to enable modern German terms to be used effectively for searching through ENHG texts.

Given the complexity of normalising ENHG, our approach was akin to a translation task, inspired by the perspective proposed by Sahle (2013) and employing a Transformer-based sequence-to-sequence model (Vaswani et al. 2017). The lack of parallel training data led us to create a synthetic corpus, applying character substitutions to modern German to simulate ENHG. While not producing authentic ENHG, this approach generated a practical basis for our normalisation model. For example, and sticking to our *wine* example, the modern German word for *wine* is *Wein*. Knowing that in ENHG it was spelt *wyn* (among others), we define a rule that substitutes *ei* → *y* and lowercases *W* → *w*, thus generating *Wein* → *wyn*.

The normalisation model, trained on 84 MB of text from the period between 1900 and 1999 from the *Deutsche Text Archiv*,[19] achieved a word error rate of 14.2%, aligning with other state-of-the-art methods (Makarov & Clematide 2020).[20] Figure 4 provides an example from the Bullinger letters, showing both the original ENHG form and its normalised version.



Farblegende: Deutsch (55.3 %) Latein (44.7 %)

S. Toto pectore cohorrui (reverende in Christo pater) cum acta illius senis legerem. Quo miser senex se vertet? Sed ego non dubito iustas fuisse causas tam gravis animadversionis. Dialogos non habeo, vidi semel tantum nec amplius. Quaerunt ex me alii, an sit suspectus de Arianismo; ego ne verbum quidem respondere possum et tamen scire cuperem; procul enim dubio se ad nos convertet. Quodsi autem Arianis faveret, neutiquam esset recipiendus. De concilio ne verbum quidem interim. Credebam dissolvendum, maxime cum omnes uno ore et tam constanter id affirmarent. Sed brevi audiemus certi aliquid. Tuas ad d. Martinengum comitem curabo; in iis hoc te monendum duxi quod ad inscriptionem Clavennam non esse in Valletelina; ist ein besondere graaffschafft.

Cläffner *wyn* und Veltlyner ist nit eins. Und darmit ich hyedurch uff den *wyn* köme, so wüssend also, das hür im summer der alt veltlyner in einem gar zimlichen gält gesyn, ursach das sich yederman versach, des nuwen wurde vyl und gůtt. Yetz sind sy bed in einem größeren gält, dan der nüw nit bym besten. Und als Balingketus hye, mit dem ich von denen dingen mich underredt, was er myner meinung, es wäre noch khein rächter gůter Veltlyner nit ußhar kommen; dan was yetz kompt, ist gesüsget und gebulveret

dazu a.R.: "Hanß Wägman und Marx Roüst sind hye oben gesyn, hand aber nit können kouffen; dan der wynen inen nit gefallen hat."

. Dem thůnd die frömbden koufflütt nott; dan in Tütschland trinckt man gern ettwas süßes, derhalben die fůr yetz thür; dan ein yeder wil mit dem süßen der erst syn. Und so 20 soum süßes kommend, find man kum 1 soum gerächten und natürlichen. Darumb so radt ich üch stil zestaan biß uff Pauli; so hoff ich, üch wol ze versorgen, so uns gott läben last, es wäre dan, das ich hyezwüschen zů einem gůten käme. Diser ist nit für üch, macht vyl flüß im houpt und unrůw im lyb.

De eo quid fieri velis, edoceas; non deero, sed consulo, ut expectes usque ad Pauli.

Ein gůter Veltlyner mag hundert jaar ligen, et nos tale bibimus. Ein gesüsgeter wäret nit lenger dan byß gegen faßnacht und den so wirt er wie ein gumpistbrüy etc.

Remitto literas Heydelbergenses et habeo gratias. Quodsi pestis nos transilit, mirum. Sed fiat domini voluntas.

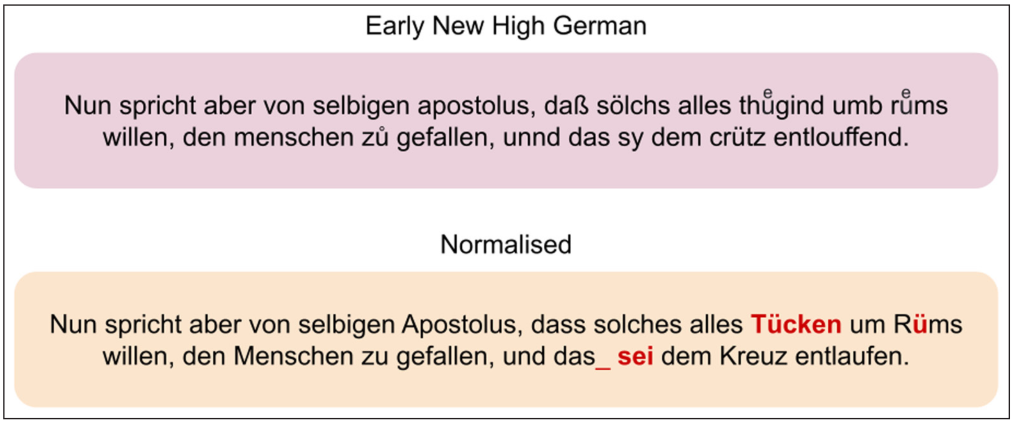
Figure 3 Visualisation of code-switching on the *Bullinger Digital* website, illustrated with a letter from Johannes Fabricius Schmid to Heinrich Bullinger (29 November 1563) (*Bullinger Digital* , 2023). Users can choose to highlight languages in different colours.

Further, we applied this model to the ENHG sentences identified in the previous language identification step (see Section 3.1 and purple box (5) in Figure 1). In Figure 4, we note a few errors in the normalisation process. We see that the model commits four errors (in red):

[18] For an in-depth exploration of this issue, Bollmann (2019) provides a comprehensive review.

[19] See https://www.deutschestextarchiv.de.

[20] Access the repository for ENHG normalisation at https://github.com/besou/textnormalization.



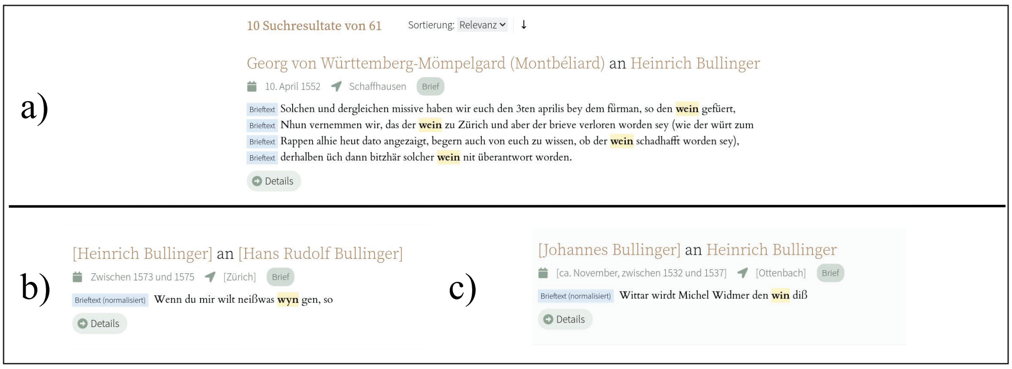
Early New High German

Nun spricht aber von selbigen apostolus, daß sölchs alles thůͤgind umb růͤms willen, den menschen zů gefallen, unnd das sy dem crütz entlouffend.

Normalised

Nun spricht aber von selbigen Apostolus, dass solches alles **Tücken** um R**ü**ms willen, den Menschen zu gefallen, und das_ **sei** dem Kreuz entlaufen.

Figure 4 An example sentence from the Bullinger letters in its original Early New High German and normalised forms.



10 Suchresultate von 61 Sortierung: Relevanz ↓

Georg von Württemberg-Mömpelgard (Montbéliard) an Heinrich Bullinger
10. April 1552 Schaffhausen Brief

Brieftext Solchen und dergleichen missive haben wir euch den 3ten aprilis bey dem fůrman, so den **wein** gefüert,
Brieftext Nhun vernemmen wir, das der **wein** zu Zürich und aber der brieve verloren worden sey (wie der würt zum
Brieftext Rappen alhie heut dato angezaigt, begern auch von euch zu wissen, ob der **wein** schadhafft worden sey),
Brieftext derhalben üch dann bitzhär solcher **wein** nit überantwort worden.

Details

[Heinrich Bullinger] an [Hans Rudolf Bullinger]
Zwischen 1573 und 1575 [Zürich] Brief

Brieftext (normalisiert) Wenn du mir wilt neißwas **wyn** gen, so

Details

[Johannes Bullinger] an Heinrich Bullinger
[ca. November, zwischen 1532 und 1537] [Ottenbach] Brief

Brieftext (normalisiert) Wittar wirdt Michel Widmer den **win** diß

Details

Figure 5 An example of a search for **a)** ENHG *wein* (EN *wine*). The search shows results for the words as entered. However, since a normalised text has been indexed, letters containing the words **b)** *win* or **c)** *wyn* (both valid variants of *wein*) are also returned.

1. *thůͤgind* should be *tun* or *tun würden* (EN *do*, *would do*).
2. *růͤms* should be *Ruhm* (EN *fame*).
3. *das* should be *dass* (EN *that*).
4. *sy* should be *sie* (EN *they*).

Despite the errors, the normalisation increases the number of relevant hits significantly. Figure 5 shows an example of this, where a search for *wein* yields hits for various word spellings, including *win* and *wyn*.

Regarding normalisation, stemming for Latin might be more effective due to fewer variations within word stems than for German. However, we plan to utilise lemmatisation, leveraging the abundant data available for training such models, potentially collaborating with resources like the *LiLa* project.[21] This promises to further enhance search accuracy and user experience.

3.3 MACHINE TRANSLATION AND MULTILINGUAL SUMMARIES

This section emphasises the reuse potential of the translations and clarifies the methodologies applied. Acknowledging Heinrich Bullinger's historical influence, we expand on the relevance and accessibility of his works to a global scholarly community, particularly in English-speaking countries.[22]

Given the intricate nature of Bullinger's Late Latin, we developed a system for dynamic translations, improving as our machine translation model evolves (detailed in the red box (4) in Figure 1). Our approach focused on German translations. We elucidate our data collection, training procedures, and model improvements in Fischer, Scheurer, Schwitter, and Volk (2022). Our methods, including pre-training and normalising Latin segments, achieved notable accuracy, clearly outperforming GoogleTranslate on our test letters (by 2.5 BLEU points).

Recent advancements, like OpenAI's GPT 3.5 and 4 models (OpenAI 2023), demonstrate superior translation quality plus robustness concerning mixed-language letters. GPT produces fluent English or German output even when translating letters that mix Latin and ENH German sentences.

[21] Refer to the LiLa project at https://lila-erc.eu/output.

[22] Scholars already translated works by Heinrich Bullinger to English during his lifetime (Opitz, 2004), indicating Bullinger's influence on the Reformation in, e. g., England.

Initial experiments also indicate the power of recent Large Language Models to summarise the letters in modern languages. For example, a prompt like ”Generate a paragraph-by-paragraph summary in English of the following letter by Heinrich Bullinger to Oswald Myconius, which is written in 16th century German and Latin:” results in surprisingly fluent and accurate texts (see Table 1). Such automatically produced summaries serve well for searches over the letters (minor errors notwithstanding) and as a basis for further professional editing. Please note the header-like start phrases for each GPT-generated paragraph.

In more detail, we will evaluate GPT’s accuracy and vocabulary appropriateness, identifying its limitations in historical contexts. The human summary in Table 1 shows the added value of disambiguating comments like “Sanherib = Kaiser Karl V.” which is difficult to achieve automatically. Our future work will include fine-tuning GPT to optimise the historical accuracy and scholarly utility.

LETTER IN ENG GERMAN AND LATIN	HUMAN SUMMARY (GERMAN) FROM THE BULLINGER EDITION	GPT-4 SUMMARY (ENGLISH)
Früntlicher, fürgeliebter herr und brůder, ich wünschen üch, üwer lieben hußfrowen und dem gantzen hußgesind von gott durch unsern herren ein gůt glückhafft jar. Des bedo̊ͤrffend wir ouch wol, dann die sachen stand gantz spitzig und gfarlich. Gott der allmåͤchtig wo̊ͤ llesich unser erbarmen.	[1] Gute Wünsche zum neuen Jahr, auch an Myconius’ Gattin [Margret] und an die Hausangehörigen. Im Hinblick auf die gegenwärtigen Gefahren kann man Glückwünsche brauchen!	[1] Greeting and New Year Wishes: Bullinger extends friendly greetings and wishes for a fortunate new year to Myconius, his wife, and household, noting the particularly perilous and critical state of current affairs. He calls for God’s mercy in these challenging times.
Ulm wil nitt vil gůts rhůmbs haben der dappfferkeit. Man mumlet, sy vertrůͤ gend sich gern mitt dem Sanherib; quod tibi dictum volo. No̊ͤ rlingen, Giengen, Boppffingen, Dinckelspühel, Rotenburg an der Tuber, Hall in Schwaben, alles und noch mee vomm keyser yngenommen! Ich bin gantz angsthafft umb den herrlichen gelerten Brentium.	[2] Die Stadt Ulm wird keine Lorbeeren für Tapferkeit ernten, denn angeblich hat sie sich recht leicht mit dem Sanherib“ [Kaiser Karl V.] ” öhnt! Dies als vertrauliche Mitteilung. Nördlingen, Giengen, Bopfingen, Dinkelsbühl, Rothenburg ob der Tauber und Schwäbisch Hall befinden sich in der Hand des Kaisers. Bullinger macht sich große Sorgen um den gelehrten [Johannes] Brenz.	[2] Military and Political Situation: He comments on the lack of bravery in Ulm and rumors of their alliance with Sanherib (possibly a metaphor for aligning with a powerful adversary). He reports the capture of several towns (Nördlingen, Giengen, Bopfingen, Dinkelsbühl, Rothenburg, and Hall) in Swabia by the Emperor. Bullinger expresses concern for the well-being of a distinguished scholar, Brentius, ...
...		
Nostri officii fuerit in tantis calamitatibus inhortari populum ad preces assiduas et ad poenitentiam. Certo, certo inveniet et nos malum istud!	[4] Im gegenwärtigen Unglück muss das Volk zum Gebet und zur Buße angehalten werden, denn bestimmt wird nun auch die Eidgenossenschaft bedroht!	[4] Religious Duty and Moral Exhortation: In light of these calamities, Bullinger feels it’s their duty to urge the people to constant prayer and repentance, with a certain belief that these troubles will also befall them.

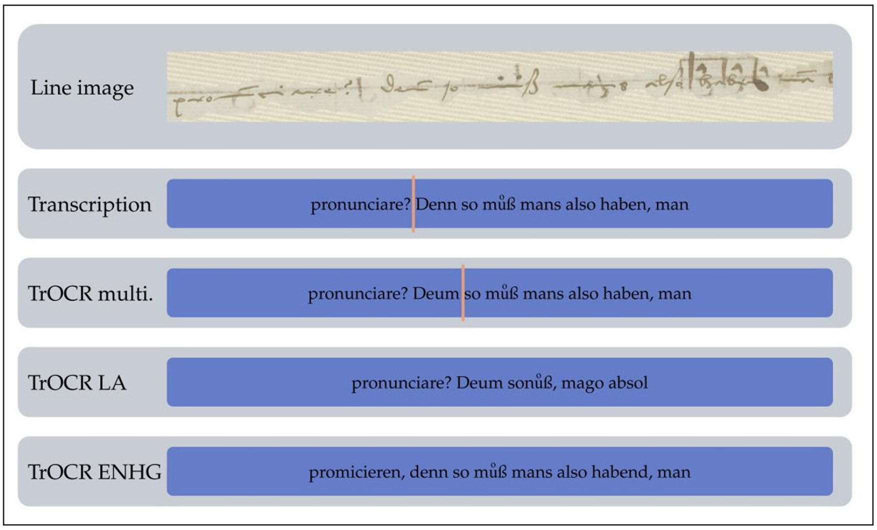
Table 1 Excerpt of the human vs. the automatic summary of a letter from Heinrich Bullinger to Oswald Myconius, 25. December 1546 (see https://www.bullinger-digital.ch/letter/12771 (*Bullinger Digital*, 2023)).

3.4 TRAINING OF HANDWRITTEN TEXT RECOGNITION FOR MULTIPLE LANGUAGES

Lastly, we summarise our work on automatic handwriting recognition in the Bullinger corpus. In our workflow (orange box (3) in Figure 1), we focus on the automatic recognition of handwriting in the remaining 3,500 untranscribed letters, utilising a large corpus of 8,700 manually transcribed letters as a foundation for training our models. We analysed the texts with our language identifier (see Section 3.1) and found that in our corpus of ~165,000 lines, 81% were in Latin and 19% in ENHG. In total, this amounts to 1.3 million words. Figure 6 presents a line image and its transcriptions. This example is also an instance in which we see a code-switch from Latin to ENHG.

Recognising the prevalence of Latin and Early New High German in the corpus, we employed the Transformer-based TrOCR model (cf. Li et al. (2021)), fine-tuning it for varying epochs and language combinations. Our experiments (detailed in Ströbel (2023)) reveal intriguing insights into the character error rates (CER) across different writer groups and language sets, as depicted in Figure 7.

The key takeaway is the pivotal role of multilingual data in reducing error rates, as a monolingual dataset significantly compromises accuracy. Our findings also underscore that the quantity of training data has a more pronounced impact on HTR performance than the language itself. The TrOCR model, refined for the Bullinger corpus,[23] produced transcriptions with an average character error rate of 7.06%, which we integrated into the searchable *Bullinger Digital* system.



Line image	
Transcription	pronunciare? Denn so mûß mans also haben, man
TrOCR multi.	pronunciare? Deum so mûß mans also haben, man
TrOCR LA	pronunciare? Deum sonûß, mago absol
TrOCR ENHG	promicieren, denn so mûß mans also habend, man

Figure 6 TrOCR model outputs demonstrating multilingual capabilities with an example of a language switch from Latin to Early New High German.

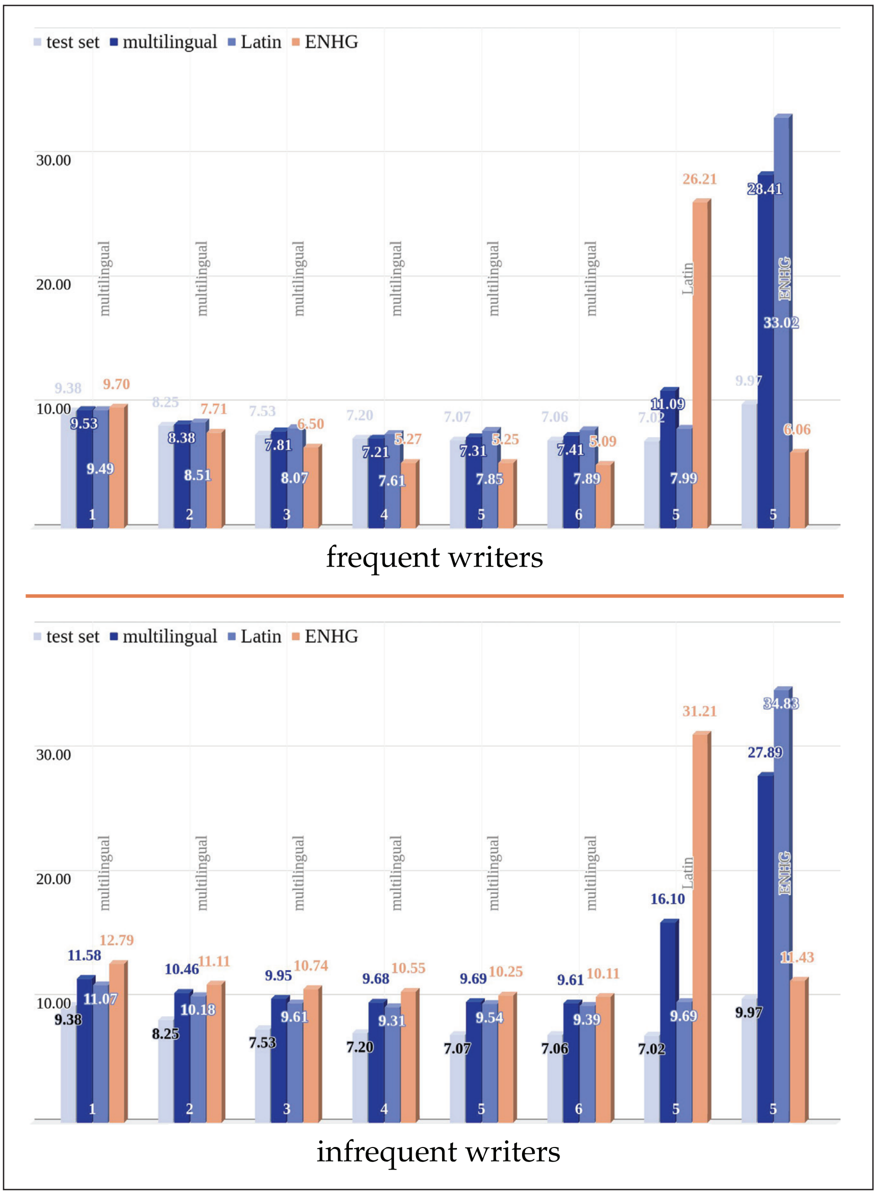


Figure 7 Comparative analysis of different HTR models, showcasing the efficacy of our multilingual approach in the Bullinger corpus.

[23] The model is available in the Hugging Face model hub: https://huggingface.co/pstroe/bullinger-general-model. The data is available on GitHub: https://github.com/pstroe/bullinger-htr.

4 CONCLUSION

This project underscores the critical role of multilingualism in historical letter editions, extending from character representation to language identification, code-switching detection, normalisation, machine translation, and handwritten text recognition. A crucial insight from our experience is the language-specificity of workflows in dealing with historical multilingual texts. For instance, the normalisation process for Early New High German (ENHG) developed in *Bullinger Digital* is not transferable to Latin.

While our initial focus was on establishing a robust textual foundation, we now plan to explore more advanced aspects. It is imperative for researchers in similar fields to recognise the importance of meticulous construction (or pre-processing) of textual bases, as these form the cornerstone of subsequent analyses and applications.

Looking ahead, we aim to develop additional tools to enhance the functionality of our web application. This includes text classification for topic identification across languages, aiming for a language-independent tagging system that can accommodate both Latin and ENHG while providing outputs in modern German and eventually English. Another ambitious goal is creating a unified semantic space for Latin and ENHG vocabularies, facilitating intuitive search capabilities. In that way, a search with the modern German word *Papst* (EN *pope*) would return letters containing ENHG *pabst* and Latin *papa*. Furthermore, integrating machine translation with AI-driven summarisation, such as leveraging GPT models, presents a promising avenue to support human editing process by automating summary generation in multiple languages for each letter, thereby streamlining scholarly research and analysis.

In conclusion, our project not only contributes to computational linguistics but also offers insights and tools for theologians and historians. We have taken steps to ensure the sustainable accessibility and applicability of our work, aiming to inspire and aid future endeavours in the digital humanities.

ACKNOWLEDGEMENTS

We want to thank all the researchers and student assistants who have been involved in this project and have contributed substantially to it. These are: Tobias Hodel, David Schoch, Anna Janka, Myrjam Hostettler, Laura Strub, Beat Wolf, Jonas Widmer, Andreas Fischer, Anna Scius-Bertrand, Martin Spoto, Angela Heldstab, Anna Mogillo, Peter Opitz, Raphael Schwitter, Judith Steiniger, Reinhard Bodenmann, David Mache, Paul Neuendorf.

FUNDING INFORMATION

We gratefully acknowledge project funding provided by various sponsors through the UZH Foundation (see www.bullinger-digital.ch/about).

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Phillip Benjamin Ströbel, Data curation, Investigation, Methodology, Formal analysis, Resources, Writing – original draft.

Lukas Fischer, Data curation, Investigation, Formal analysis, Software, Resources. Raphael Müller, Data curation, Investigation, Visualisation, Software.

Patricia Scheurer, Project administration, Supervision, Data curation, Resources. Bernard Schroffenegger, Data curation, Investigation, Software.

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TO CITE THIS ARTICLE:
Ströbel, P. B., Fischer, L., Müller, R., Scheurer, P., Schroffenegger, B., Suter, B., & Volk, M. (2024). Multilingual Workflows in *Bullinger Digital*: Data Curation for Latin and Early New High German. *Journal of Open Humanities Data*, 10: 12, pp. 1–13. DOI: https://doi.org/10.5334/johd.174

Submitted: 16 October 2023
Accepted: 20 December 2023
Published: 24 January 2024

Journal of Open Humanities Data is a peer-reviewed open access journal published by Ubiquity Press.