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Revealing 'invisible' poetry by W. H. Auden through computer vision: Using photometric stereo to visualize indented impressions

Simon Brenner [1], **Timo Frühwirth** [2,*], **Sandra Mayer** [2]

[1]Computer Vision Lab, TU Wien, Vienna, Austria
[2]Austrian Centre for Digital Humanities and Cultural Heritage, Austrian Academy of Sciences, Vienna, Austria
*Correspondence: Timo Frühwirth, Austrian Centre for Digital Humanities and Cultural Heritage, Austria. E-mail: timo.fruehwirth@oeaw.ac.at

Abstract

This article explores the use of computer-vision technologies in the context of digitally editing and researching letters and literary papers by the British-American poet W. H. Auden. Two documents in the previously inaccessible 'Auden Musulin Papers' contain colourless indented typewriter impressions of poetry. These impressions result from the papers' original use as 'backing sheets', inserted into a typewriter below those sheets of paper on which Auden typed his poetry. Subsequently, these backing sheets were reused in the poet's 'working correspondence' to Welsh-Austrian writer Stella Musulin. While standard image-digitization technologies fail to capture these 3D indented impressions, they can successfully be represented by means of Photometric Stereo, which has been fruitfully employed in the research of 3D cultural-heritage objects. Following a detailed outline of this method, this article demonstrates how Photometric Stereo can help to reconstruct poetry that has survived only in the form of indented impressions. Thus, the case study illustrates how computer vision can contribute to our understanding both of 'poetic' practices of composition and revision as well as of 'material' writing practices. It also has wide-ranging implications for re-conceptualizing sheets of paper as 3D objects in the research of literary documents from the twentieth century.

1 Introduction

There has long been a 'material turn' in literary studies that explores and acknowledges the impact of mediality and material conditions on literary production, consumption, and reception (McGann, 1991; McKenzie, 1999), including textual genesis, archival scholarship, book design, print, and writing technologies, as well as print cultures and publishing industries (see, for instance, van Hulle, 2004; Eliot and Rose, 2009; Bidwell, 2019; Sutherland, 2022). (Digital) editing scholarship and practice have also increasingly been paying attention to questions of materiality, mediality, and performativity of communication, demonstrating the relevance of the tools, materials, and specific qualities of writing; of the physical carriers of text; and of the historical and individual practices of writing for the analysis and interpretation of (not only) literary documents (Schubert, 2010; Lukas *et al.*, 2014).[1]

Even more recently, the 3D surface structures of cultural-heritage objects, including (near-flat) text and image carriers such as medieval parchment, renaissance drawing paper, eighteenth-century copperplate prints, Sanskrit palm-leaf manuscripts (Vandermeulen *et al.*, 2018; Endres, 2019; Barrett, 2022), or papyri (Kotoula and Earl, 2015; Piquette, 2017) have attracted scholarly interest. At the same time, methodological conventions in digital scholarly editing still tend to treat objects such as manuscripts as 'two-dimensional material', as stipulated by the *Metamorfoze Preservation Imaging Guidelines*, one of the internationally recognized standards in cultural-heritage image digitization (van Dormolen, 2019, p. 9).

Departing from both this reductive approach to manuscript material as 2D and the focus on older carriers of text, we propose that the study of literary papers from the 'typewriter age' as 3D objects can yield valuable insights into the processes of literary production, specifically the practices of composition and revision as well as the material practices of writing. In the following, our case study of reconstructing surface details of letters and literary papers written by poet

W. H. Auden in Austria will demonstrate how shedding light on literary documents from a new 'angle' (or, quite literally, six angles) can enrich the study of literature in the context of the 'material turn'.[2]

Aiming to make our methodological approach replicable in scholarly practice, we provide techniques for efficiently capturing and visualizing such surface details using standard photometric stereo (PS) and a simple hardware setup. We are able to sidestep common problems of PS under non-parallel illumination by taking advantage of the almost-flat shape of documents: spatially varying light directions are handled by computing local light directions and solving PS for small surface patches, and light attenuation effects are eliminated from the input images via calibration images of a uniformly coloured surface approximately coplanar with the document. Easily interpretable visualizations are created by combining high-pass filtered depth maps and albedo maps.

2 A digital edition of W. H. Auden's letters and literary papers in Austria

The British-American poet W. H. Auden (1907–73) is widely considered one of the most influential writers in the English language in the twentieth century. Born in England, he relocated to the USA in 1939, where he settled in New York City and became a naturalized citizen in 1946. In 1948, he received the Pulitzer Prize for Poetry for his 1947 book-length poem *The Age of Anxiety*; he was awarded the National Book Award for his poetry collection *The Shield of Achilles* in 1956. In the same year, he took up the Professorship of Poetry at the University of Oxford, which lasted until 1961 and prompted his periodic return to his *alma mater*.

In the late 1940s, Auden began spending extended periods of time also in other parts of Europe, first on the Italian island of Ischia, where he rented a summer home, and, from 1958, in the Austrian village of Kirchstetten, where he owned a house together with his partner and artistic collaborator Chester Kallman. Until his death in 1973, he spent up to 6 months of each year in Austria; it was there that he wrote most of his late poetry (Quinn, 2013, p. 56; Quinn, 2015, p. 243), including the 1965 sequence of autobiographical poems 'Thanksgiving for a Habitat', which makes reference to the individual rooms of Auden's Austrian home. Moreover, the Kirchstetten house was the site of Auden and Kallman's collaborations with composers Hans Werner Henze and Nicolas Nabokov (Carpenter, 1981, pp. 398, 400, 429; Osborne, 1995, pp. 262, 289).

In Auden scholarship, Auden's English and American periods have been extensively researched whereas his life and work in Italy and Austria have long remained under-investigated. Only since around 2000, Auden's Austrian period has attracted increased international scholarly interest (Mendelson, 2005; Smith, 2005). In Austria, two collections of essays have outlined the contours of an emerging field of Austrian Auden Studies (Denzer and Seidl, 2014; Neundlinger, 2018), contributing to a reevaluation of this highly prolific late period in W. H. Auden's life.

The 'Auden Musulin Papers' project, based at the Austrian Centre for Digital Humanities and Cultural Heritage of the Austrian Academy of Sciences, casts a fresh light on the poet's life and work in Austria through a previously inaccessible, private collection of Auden's 'working correspondence' (Musulin, 1995, p. 211) with Welsh-Austrian writer Stella Musulin. The project results in a digital edition (https://amp.acdh.oeaw.ac.at) that makes openly accessible the private messages as well as literary papers, drafts of public speeches, and photographs that form part of this collection. The edition offers transcripts of all written documents together with digital facsimiles, indices, and interactive maps. The project has availed itself of standard digital-edition technologies, including TEI-XML for transcription and markup as well as digital photography. In the course of image digitization, we encountered specific challenges that will form the subject of the following discussion.

3 'Invisible' poetry: typewriter impressions left by literary production

3.1 The type-'writing scene' in the Kirchstetten study

Among the Auden Musulin Papers, we found two documents that contain indented impressions of lines of poetry written on the poet's typewriter—the 'Olivetti Portable' immortalized in Auden's poem 'The Cave of Making', the third poem in 'Thanksgiving for a Habitat'. The poem portrays the 'writing scene' in the lyrical speaker's study as the historically conditioned and writer-specific interplay of semantic, technological, and bodily aspects of writing (Campe, 2021, pp. 1122, 1125)[3]:

> . . . from the Olivetti Portable,
> the dictionaries (the very
> best money can buy), the heaps of paper, it is evident
> what must go on. Devoid of
> flowers and family photographs, all is subordinate
> here to a function, designed to

discourage daydreams—hence windows averted from plausible
videnda but admitting a light one
could mend a watch by—and to sharpen hearing . . .
. . . Here silence
is turned into objects. (Auden, 2022a, pp. 508–9)

Footage from a 1967 Austrian TV documentary shows Auden's Olivetti typewriter on the poet's desk in the midst of heaps of paper. Auden was a poet of the typewriter age, roughly spanning the century from the 1880s until the 1980s, when the typewriter was the key writing technology, next to pen and paper, in literary production (Lyons, 2021, pp. 7, 13). Then, it was standard practice to insert a 'backing sheet' into the typewriter below that sheet onto which the typebars transferred the ink from the intermediate ribbon, in order to alleviate the type's impact on the paper and the rubber platen (Bailey, 1990, p. ix; Rajkay, 2022).[4] In two instances, we have proof that Auden also adopted this practice in his Austrian 'Cave of Making', where he reused backing sheets for his correspondence and literary writing. These sheets contain inkless indented impressions that were created when the pressure of the striking typebars pushed through to the second page. The 3D impressions have been overwritten by texts sent by W. H. Auden to Stella Musulin: in one case, by the typescript of a German-language translation of Auden's poem 'Joseph Weinheber' (Auden, 2023a); in the other case, by a short handwritten note addressed to Musulin (Auden, 2023b). As the editors of the Auden Musulin Papers digital edition, we have faced the challenge of uncovering, and making available, these hidden layers of text.

3.2 Initial attempts at visualizing the indented impressions

By means of illuminating the documents in question through raking light (i.e. strong light emanating from an oblique angle), the indented impressions in these Auden documents become visible, but remain largely undecipherable (see Figs 1 and 2). Oblique lighting is a forensic method used to examine documents that contain handwritten or typewritten impressions, for instance, in order to identify the author of an anonymous ransom note (Allen, 2015, pp. 199, 206–7).[5] Raking light has also been successfully applied in the study of text carriers in the cultural-heritage field.[6] However, in one of the Auden documents in question, the colourless impressions are largely overwritten by the inked (as well as impressed) lines from a typescript of a German-language prose translation of Auden's poem 'Joseph Weinheber', sent to Stella Musulin on 28 April 1965 (Auden, 2023a, see Fig. 1). For the second document, a brief handwritten note addressed to

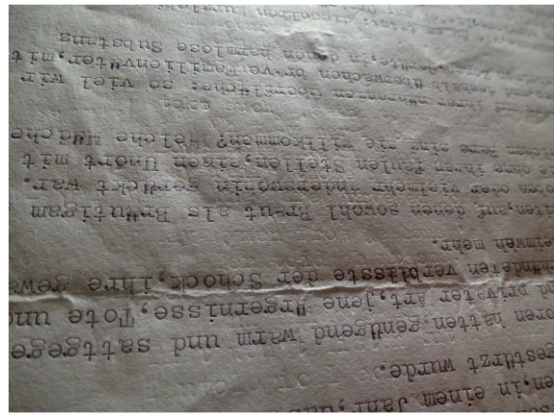

Figure 1. Illuminating the typescript of 'Joseph Weinheber' from 28 April 1965 by means of raking light

Figure 2. Illuminating Auden's letter from 10 June 1969 by means of raking light

Musulin and sent to her on 10 June 1969, Auden reused a backing sheet that had been flipped around when inserted below another sheet in the typewriter (Auden, 2023b). The page thus contains overlapping lines in opposite (i.e. in standard and mirror-image) orientations (see Fig. 2). In both cases, the impressed texts cannot be fully retrieved from the multiple, multidirectional layers of writing and overwriting by means of raking light only.

In the context of the Auden Musulin Papers edition project, the two documents were first digitized by means of a standard digital camera setup using a Phase One XF IQ3 100MP medium-format camera. That setup was configured to meet the strictest requirements of the Federal Agencies Digital Guidelines Initiative (FADGI) and Metamorfoze imaging standards for the cultural-heritage sector (van Dormolen, 2012, 2019; FADGI Federal Agencies Digital Guidelines Initiative, 2022).[7] The digital images resulting from that

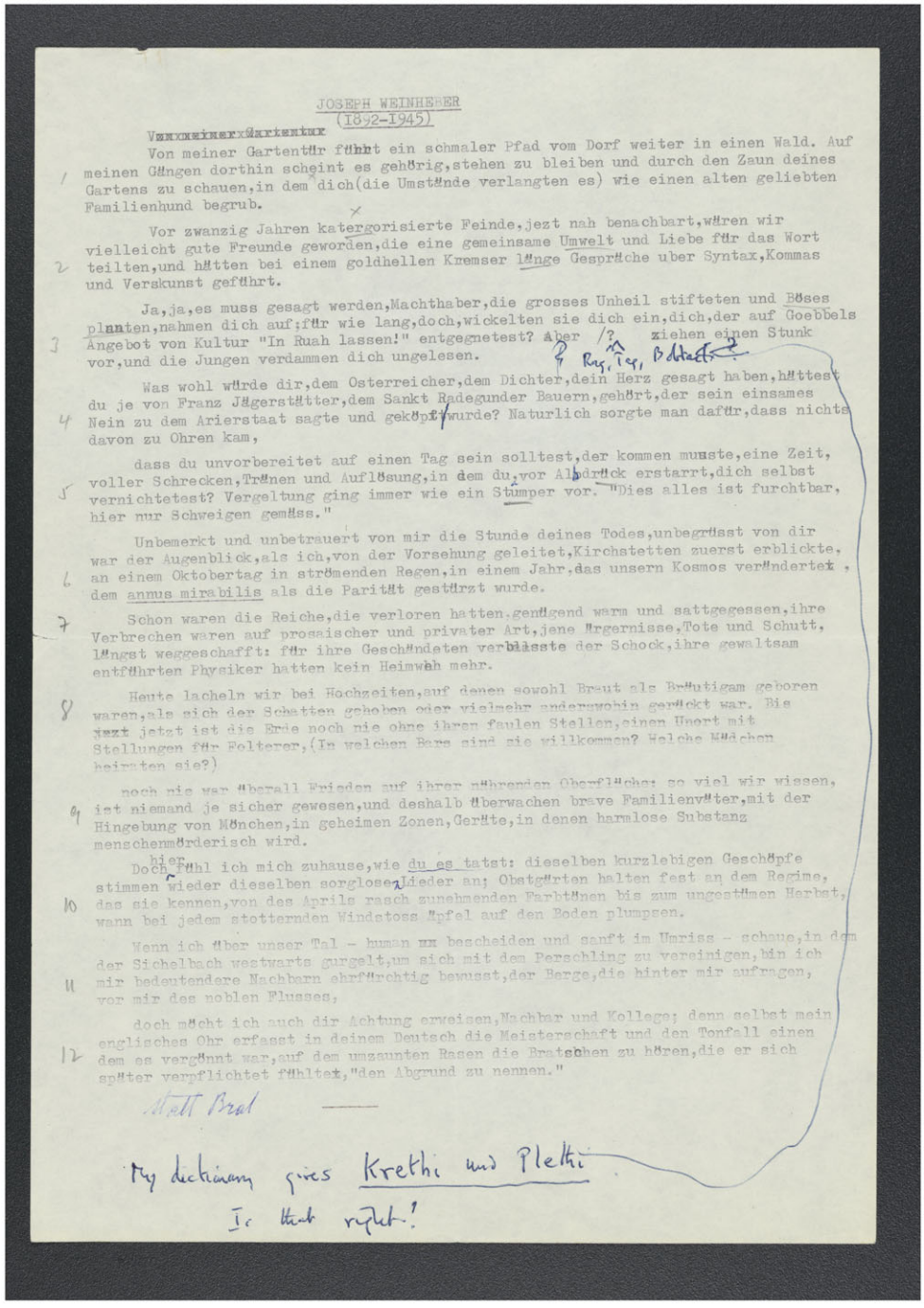

Figure 3. Digital facsimile of the typescript of 'Joseph Weinheber' from 28 April 1965, created by means of medium-format digital photography

photographic reproduction do not capture the indented impressions contained in the sheets of paper (see Figs 3 and 4). In the image of the 1965 document, neither impressions nor any other traces of the original typescript (under which this page was once inserted into the typewriter) are depicted: only the typescript of 'Joseph Weinheber' as well as handwritten annotations and corrections are visible (see Fig. 3). In the digital

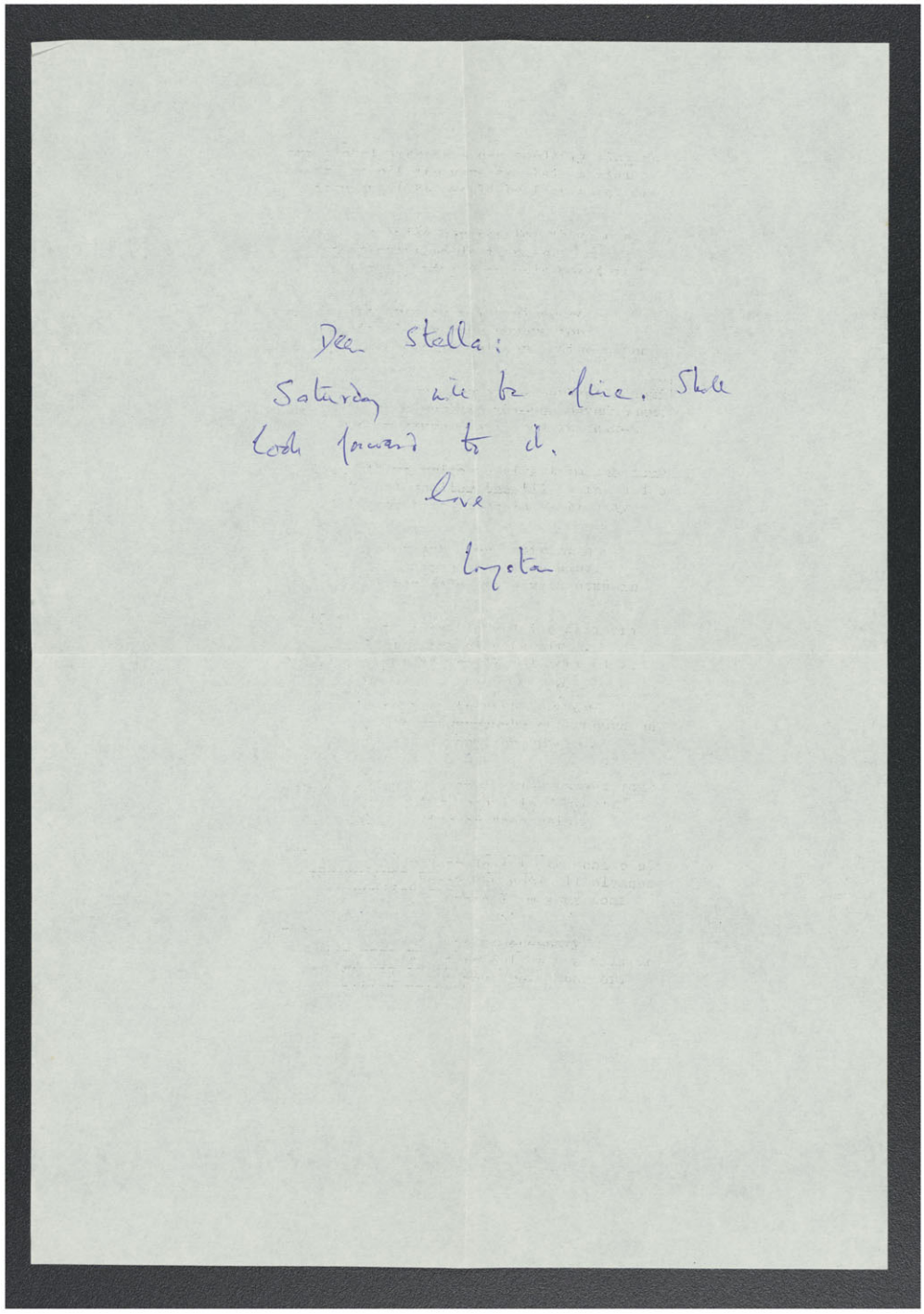

Figure 4. Digital facsimile of Auden's letter from 10 June 1969, created by means of medium-format digital photography

facsimile of the 1969 letter, only traces of ink can be seen that would seem to have been transferred onto the backing sheet when the top page, containing fresh ink, was turned around (see Fig. 4).

The digital images obtained through standard (i.e. FADGI-compliant, perpendicular-angle) image-digitization technologies fail to capture the 3D indented impressions in the documents' surface

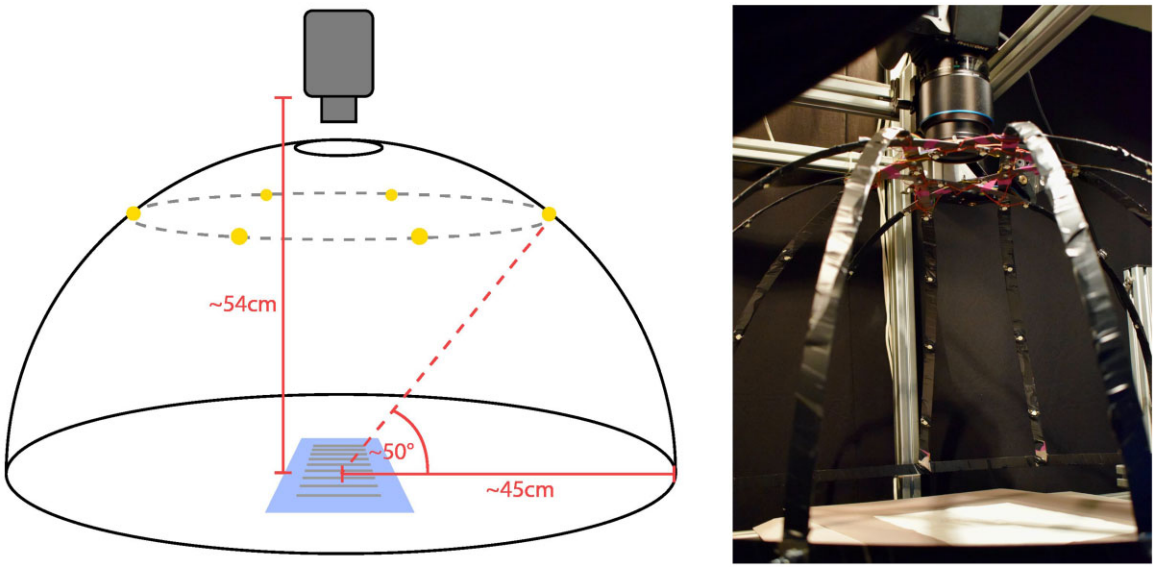

Figure 5. The light dome used for acquiring images under different illumination directions. The schematic illustration on the left shows the locations of light sources (yellow), camera (grey), and document (blue). The acquisition setup for imaging the letters is shown on the right; during acquisition, ambient light was eliminated

topography and to render readable the texts that these impressions contain. Thus, important material aspects of the documents in question remain unrepresented and inaccessible as subjects of scholarly inquiry. In the search for alternative methodological solutions, therefore, we have taken advantage of the extended potentials of computer-vision technologies that are employed in the research of cultural-heritage objects.

4 Computer vision: visualization through photometric stereo

PS is a computer-vision method for the reconstruction of surface orientation and depth from a set of images with constant camera parameters and varying lighting directions (Woodham, 1980). In comparison to other 3D acquisition methods (e.g. structured light scanning or photogrammetry), PS is especially efficient for the acquisition of local surface details (Herbort and Wöhler, 2011). Aside from applications in industrial surface inspection (Jackson *et al.*, 2007; Thumfart *et al.*, 2013), PS has been used to separate handwriting from printed background text based on the impressions left by the pen (McGunnigle and Chantler, 2003). In the case study treated in this paper, PS is applied for the visualization of typewriter impressions, allowing for their transcription and further use in scholarly analysis. The workflow from image acquisition to PS reconstruction and post-processing for visualization is elaborated in the following sections.

4.1 Image acquisition

For illumination, we used a hemispherical dome construction with a radius of ca. 45 cm, equipped with fifty-four high-power white light emitting diodes (LEDs). Due to efficiency considerations and previous experiments with similar objects (Brenner *et al.*, 2018), only a subset of six LEDs in a circular arrangement at a ca. 50° elevational angle from the centre of the hemisphere was used for this work. A camera was placed above the opening at the top of the dome (see Fig. 5). We used a PhaseOne IQ260 Achromatic with an 8,964 × 6,716 pixel medium-format sensor and a Schneider-Kreuznach 120 mm LS Macro lens. At an imaging distance of ca. 54 cm, this leads to a surface resolution of 40.55 pixels per millimetre (∼1,030 dpi). In this configuration, only half of the original A4 format fits in a single image. Acquisition was performed in a fully darkened environment to ensure that the currently active LED was the only light source.

4.2 PS reconstruction

In the original formulation of PS (Woodham, 1980), several assumptions about the imaged object and the imaging setup are made that allow for a straightforward solution, including a diffusely reflecting surface and parallel lighting. While in our application the surface of interest (matte paper) is indeed mostly diffuse, the assumption of parallel lighting is problematic. When using point light sources, the direction and the distance to the light source are different for each surface point; thus, different intensities are measured at points with equal surface orientation. These deviations from the parallel

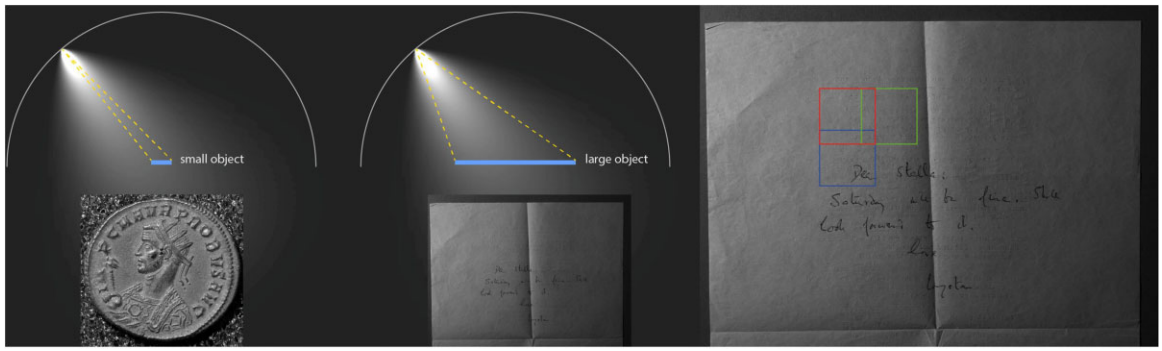

Figure 6. The larger the object in comparison to the lighting distance, the less accurate the parallel lighting assumption. In the example to the left, the distance and angle to the light source vary only minimally across the surface of the coin; for the much larger sheet of paper imaged with the same setup (middle), distance and angle vary substantially. This can be observed qualitatively with regard to the brightness variations across the resulting images. On the right, our patch-wise processing approach is illustrated with three overlapping patches: within any one patch, the lighting variations are tolerable

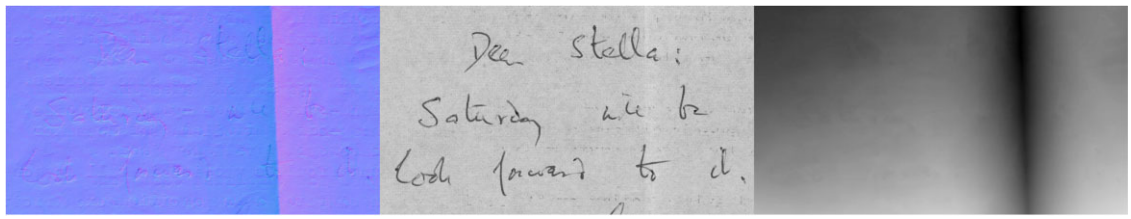

Figure 7. Normal map (left), with *x*-, *y*-, and *z*-components of the surface normal vector at each pixel position being encoded in the red, green, and blue channels of an RGB image. The albedo map (centre) shows the surface brightness (as a material property). The depth map (right) encodes the distance from the camera to the imaged surface, with darker colours corresponding to greater distances from the camera

lighting model increase with the size of the object in relation to the distance of the light sources (see Fig. 6); in our imaging setup, PS methods using a parallel-lighting model have produced intolerable distortions.

Various PS approaches for near point lighting setups have been published (Mecca *et al.*, 2014; Quéau *et al.*, 2017; Xie *et al.*, 2019; Lichy *et al.*, 2022), but they come with the need of cumbersome light-source calibration (in relation to position, intensity, principal direction, and anisotropy) and/or high computational complexity. In this case study, we demonstrate that we can arrive at the desired reconstruction of typewriter impressions by much simpler means, in that the objects investigated (paper sheets) are near planar and the focus of interest lies in local details (typewriter impressions) and not in the global shape of the object.

Therefore, we resort to a hybrid approach that consists of solving PS locally for small surface patches and combining the results afterwards. In order to compute a local lighting direction for each of these patches, first the light-source positions are estimated using highlights on reflective spheres (Powell *et al.*, 2001). Then, assuming a planar object surface perpendicular to the viewing direction at a known distance, the computation of local light directions is straightforward. The remaining problem of light attenuation is approached by an additional pre-processing step: the intensity distribution of a uniformly coloured diffuse reference plane is compared with a synthetic image rendered under the Lambertian lighting model and the known imaging setup. The measured deviation is then used to correct the input images. This is an improved version of the pre-processing suggested by Sun *et al.* (2013). By means of inputs that were thus pre-processed and estimated local light directions, PS can be solved efficiently using the original formulation (Woodham, 1980), resulting in a normal map and an albedo map for each patch. As illustrated on the right in Fig. 6, the patches are overlapping in order to enable a seamless blending of the partial results by feathering (Ghosh and Kaabouch, 2016). Surface depth is obtained via integration (Simchony *et al.*, 1990) of the blended normal maps. Examples of a normal map, albedo map, and depth map of a page section are shown in Fig. 7.

4.3 Post-processing

The images shown in Fig. 7 are not particularly useful for reading the typewriter impressions. Especially, in the depth map, depth variations introduced by

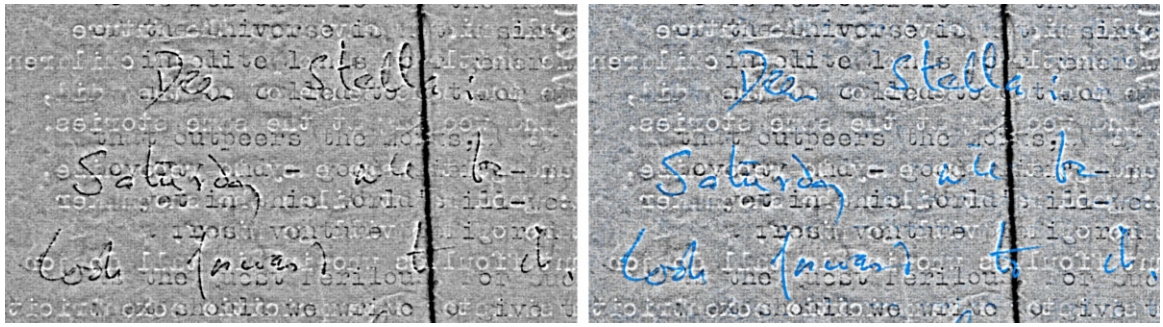

Figure 8. PS results processed for visualization. High-pass filtered and contrast-enhanced depth map (left): pixels darker than the background correspond to impressions from the viewer's side, pixels brighter than the background show impressions from the opposite side. A blend of the depth map and the albedo map (right) for a better distinction of impressions made by typewriter (black) and pen

typewriter impressions are very small compared with global depth variations of the paper (folds, bends, etc.), so that they are not visible in a naive visualization. To resolve this problem, a high-pass filter is applied in order to preserve only fine details and flatten out large-scale variations. The high-pass filter is implemented as a subtraction of a Gauss-filtered version of the depth map (with $\sigma = 0.25$ mm, determined experimentally) from the original.

For visualization, the resulting depth values are mapped to grey values so that $\mu - 3\sigma$ corresponds to the minimum intensity value of a digital image and $\mu + 3\sigma$ corresponds to the maximum (where μ is the mean depth and σ is the standard deviation). The resulting image is shown on the left of Fig. 8, in which letters darker than the background correspond to impressions from the viewer's side (recto) and letters brighter than the background correspond to impressions from the opposite side (verso). Note that the handwriting and one set of typewriter impressions are shown in similar grey values. To achieve a clear distinction between the originally coloured text sources and the inkless impressions, the depth map can be combined with the albedo map. On the right of Fig. 8, an example of such a combined image is shown. The full visualizations of all relevant pages are available on Zenodo.[8]

4.4 Conservational aspects

Every measurement performed on original historical material poses a risk that must be in due relation to the expected benefits. PS is a non-contact measurement method, which means that the only source of potential harm to the object is the radiation emitted by the light sources. As the white LEDs used in our setup do not emit UV radiation and heat development is negligible, the only potential source of harm is visible light.

In order to quantify the radiation load on the object, we have measured the illuminance at the centre of the light dome for each installed LED. Depending on the position of the LED, the illuminance varies between 18 and 147 lux, with an average of 73 lux across all LEDs. Assuming a long exposure time of one second per image and an acquisition using all fifty-four available light positions, the total imaging process amounts to 1.1 lux hours of light exposure. In comparison, for objects on display in museums, the CIE guideline on Control of Damage to Museum Objects by Optical Radiation (International Commission on Illumination, 2004) recommends an illuminance of 50 lux and an exposure of 15,000 lux hours per year for the most sensitive objects. This means that the light exposure induced by our image acquisition process is equivalent to displaying the object in a museum for about one and a half minutes. Or, assuming a workplace with a recommended minimum illumination of 200 lux (International Organization for Standardization, 2002), the procedure amounts to the same light exposure as viewing the document on a working desk for about 20 seconds.

5 Discussion of results

The two scenarios that might be anticipated as outcomes of reconstructing typescripts from indented impressions are (1) that the retrieved typescript corresponds to an original document that is now housed in an archival collection and (2) that the reconstruction represents a previously unknown typescript. Both scenarios are exemplified by the two documents of our case study: while the Photometric-Stereo analysis of Auden's letter to Musulin from 1969 has revealed an unpublished version of the poet's 'Epistle to a Godson' that corresponds to a document now held by the Bodleian Libraries, the surface of the 1965 translation of Auden's 'Joseph Weinheber' contains an unknown early version of the poem 'Epithalamium' that must be assumed lost.

5.1 An unpublished version of Auden's poem 'Epistle to a Godson'

W. H. Auden's poem 'Epistle to a Godson' was first published in June 1969 in *The New York Review of*

Books (Auden, 1969a), and appeared later in his 1972 book of poems *Epistle to a Godson and Other Poems* (Auden, 1972). The poem contains an explicit autobiographical reference to Auden's residence in Kirchstetten. Its first two lines address the poet's godson Philip Spender: 'DEAR PHILIP. "Thank God for boozy godfathers"/you wrote in our guest-book' (Auden, 2022b, p. 649). Philip Spender, the nephew of one of Auden's oldest friends, Stephen Spender, had visited Auden and Kallman in Austria in 1968. His entry in the Kirchstetten guest book, which is now housed at the Harry Ransom Centre, University of Texas at Austin, is dated 15–21 September 1968 and reads: 'Thank God for boozy Godfathers, thank Chester for marvellous tastes' (qtd in Carpenter, 1981, p. 389).

For the largest part, the poem could be retrieved from the Photometric-Stereo visualizations and has been transcribed in TEI-XML. The transcript reveals a previously unpublished version of the poem. Combining textual features—verbal variants, spelling, and punctuation—of both the 1969 and 1972 texts, it can be described as a preliminary, intermediate version of 'Epistle to a Godson' that has never been printed in this form. Based on this specific shape of the text as well as on typewritten deletions and additions, the indented impressions in Auden's letter to Musulin have been identified as originating from a typescript of 'Epistle to a Godson' sent by Auden to E. R. Dodds (Auden, 1969b), an Oxford classical scholar and lifelong friend of the poet. This typescript forms part of a letter sent to Dodds from Kirchstetten on 10 June 1969, in which Auden explicitly refers to the enclosed poem, and which is now held in the Bodleian's Special Collections. Already including textual features that distinguish the later, 1972, edition of the poem, this 1969 typescript evidences a swift mode of poetic revision—a process set in motion soon after the poem's first, and years ahead of its last, publication during the poet's lifetime.

The enclosed poem is undated and written on a type of paper that is different in size and quality from that on which the letter is written. Thus, the typescript might potentially have been created at an earlier point in time. However, the Photometric-Stereo method generates information that goes beyond the reconstruction of the actual text and provides contextual evidence that helps date the poetic typescript. The text has been retrieved from indented impressions in Auden's short handwritten note to Musulin on a sheet of paper previously used as a backing sheet for the Dodds typescript. Both carry the Kirchstetten postmark '10.-6.69-18', meaning that both letters were dispatched from the Kirchstetten post office on 10 June 1969, between 5 and 6 o'clock in the early evening. This additional piece of information yielded by the Photometric-Stereo visualization, revealing the spatio-temporal proximity of the two messages, strongly suggests that the typescript of 'Epistle to a Godson' was written shortly before sending off the two communications to Musulin and Dodds.

5.2 A lost early version of 'Epithalamium'

Four years earlier, on 28 April 1965, Auden had sent to Musulin the typescript of a German-language prose translation of his poem 'Joseph Weinheber'. For this typescript, Auden reused a sheet of paper originally used as a backing sheet below another typescript: that of his poem 'Epithalamium', also an autobiographical poem, written to mark the occasion of his niece Rita Auden's wedding to Peter Mudford on 15 May 1965. The text of the poem that has been reconstructed by means of PS is unique: it cannot be related to any published versions of the poem or any poetic typescript held by any public archive. It has survived only in the form of indented impressions, and is here printed for the first time. In the following, the poem's text is diplomatically transcribed including blank spaces and deletions, with square brackets indicating passages which cannot be rendered with certainty or are entirely illegible. The full TEI-XML transcription is available via Zenodo.[9]

[A]ll folk-t[a]les mean that end with
A palace wed[d]ing,
[]eas~~r~~ts and fireworks, we wish you,
[]eter and Rita,
Two idiosyncr[][c]ies
[]o opt in this [h]awt[h]orn [m]o[n]th
[]o [c]o[mm]on your li[ve]s[,]

[] diffy undertaking,
[]or, t[o] thos[e] who[se] dr[]s
[]e [o]dorl[]s, [w]h[]t [i][] r[ea]l
[]eems r[]th[]r []elly[:]
[]tr[]ng [n][]rv[][s] are [][n] a[]
v[]nt[]ge;
[A]n [a]ccurat[e] [w]rist-watch, too,
[C][]n be a [g]reat hel[p].

[][ay] Venus, to wh[os]e []a[][r]ice
[]ll blood [m]ust []u[]om,
t[~~e~~a]k~~t~~[e] such a shine to you both
Th[]t [b]y her favor
Your p[a]lpable subtances
[]ay rei[f]y those deli[g]hts
They are purveyed for.

[M]ay [H]ymen from jealousy's
Teratoid ph[]n~~[r]~~tasms,
[]o[]p[e]tit~~v[e]~~ive s[ce]n[e]s [a]nd
su[][s,]
[A]nd pride's monologu[e]
That won't listen but demands
Tautological echoes,

[]ver [de] [] [e] [] you.

As genders, m[a]rried or not,
[]ho share with all flesh
[A] left-han[]ed twist, to-day
[]e thank []rs. []ind,
[]or, [a]ll in [a]ll, [s]he h[a]ds do[n]e
([]ur ugly looks are our [d]eed)
The handsome by us.

[W]e are better built to l[]st
Th[]n tigers, our skins
[]on't leak like the ciliates,
[]ur [ea]rs can detect
[]u[]rter[-]tones, even our most
[]yopic have good enough
Vision for courtship.

Besides, it's a miracle
[]e're here to say so,
Th[]t [l]i[]e should have go[t] to us
[U]p through the city's
[De]struction layers after
Surviving the inhuman
[]ermi[]n []urg[e]s.

'Epithalamium' was first published in *The New Yorker* on 31 July 1965 (Auden, 1965). The restored poem substantially deviates from that text. Already the prominent first two lines differ markedly: instead of 'All folk tales mean by ending/with a State Marriage', the retrieved poem has 'All folk-tales mean that end with/A palace wedding'. Moreover, there are significant verbal variants (in lines 1–3, 9, 11, 18, 22, 24, 28, 31–34, and 43) as well as differences in spelling (lines 22, 25, 45, and 46) and punctuation (lines 9, 18, 20, 21, 35, 40, and 42). As opposed to the *New Yorker* version, all line beginnings of the reconstructed text are capitalized.

The Photometric-Stereo method has not only allowed us to recover this previously unknown textual version of the poem, but has also yielded crucial contextual information related to Auden's *poetic* practices of composition and revision as well as the *material* writing practices employed in his Austrian workshop. Auden submitted the *New Yorker* poem for publication on 29 May 1965 (Mendelson, 2022, p. 1027). The above version has been retrieved from the typescript of 'Joseph Weinheber' sent to Musulin on 28 April. The original typescript of 'Epithalamium', below which that sheet had been inserted into the typewriter as a backing sheet, therefore, must have been written at least a month before Auden submitted the final version to *The New Yorker*.

A further detail has led us to conclude that this early version of 'Epithalamium' was written on 28 April 1965, the day on which he sent his 'Weinheber' translation to Musulin. On that day, Auden wrote in his pocket diary: 'Epithalamium done but for names' (qtd in Mendelson, 2022, p. 1027). The restored poem includes 49 lines as opposed to the 63 lines of the poem published in *The New Yorker*. It breaks off immediately before an enumeration of names: the family names of the bride and bridegroom as well as the names of their mothers' families ('Mudfords, Audens/Seth-Smiths, Bonnerjees'). It would seem plausible to assume that Auden made enquiries about those names before noting in his diary, on 5 May, that he had 'received names' (qtd in Mendelson, 2022, p. 1027). These details suggest that, immediately reusing the backing sheet for his communication to Musulin, he may have kept this early, incomplete, version until he would be able to finish the poem. Subsequently, he may have disposed of it once it was superseded by a newer, complete, and possibly further revised version of the poem.

In the light of this evidence, it seems plausible that the restored text was the first instantiation of the poem that the poet himself would consider as 'done', even though still incomplete and subject to further revision. Thus, it marks a distinctive point in the development of the poem that can be approximately situated between two different stages in the poetic composition distinguished by two different writing technologies. As Hannah Sullivan points out, Auden would draft poems in longhand in his notebooks (Sullivan, 2015, p. 15); switching to the typewriter would coincide with another, more advanced, stage of poetic composition. Sullivan relates this use of the typewriter to Auden's own comment on the defamiliarizing effect of typescript (Sullivan, 2015, p. 15): 'Most people enjoy the sight of their own handwriting as they enjoy the smell of their own farts. Much as I loathe the typewriter, I must admit that it is a help in self-criticism. Typescript is so impersonal and hideous to look at that, if I type out a poem, I immediately see defects which I missed when I looked through it in manuscript' (Auden, 1962, p. 17).

Whereas, for Auden, handwriting might have been the appropriate writing technology at the stage of composing intricate syntactic structure and metrical form (Sullivan, 2015, pp. 6, 16), the differences between the restored text of 'Epithalamium' and its published version would seem to indicate that Auden would consider the typewriter appropriate for applying smaller-scale revisions and finishing touches. Pertaining especially to word choice, spelling, and punctuation, these would leave the poem's syntactic structure largely unchanged. Thus contributing to the research of both poetic and material writing practices, this case study has farther-reaching implications for the potentials of visualizing indented impressions through computer vision in the

study of literary papers that will be addressed in the following section.

6 Implications and conclusion

The visualizations generated by means of PS and the transcriptions of the texts they have made visible will be integrated into the digital edition of the Auden Musulin Papers. They will enable further research by unlocking information contained in the material objects that has been inaccessible to standard digitization methods.

Beyond this specific use of these particular materials, the case study has wider implications with regard to how computer vision can be fruitfully employed to make hidden layers of text accessible. Especially, we identify the following three key ramifications. First, the study of the Auden documents suggests that computer vision can contribute to our understanding of poetic practices of composition and revision. By means of reconstructing typescripts that may only have survived in the form of indented impressions, we can retrace the specific stages in the creative development of poems. The use of backing sheets was a standard practice during the typewriter era, and, through establishing spatio-temporal relationships between the texts contained in the impressions of these sheets and the messages overwriting them, the textual information can be enriched by *con*-textual data.

Second, in addition to this genetic-semantic angle, computer vision can provide evidence of the individual material writing practices during an era when the typewriter was the key writing technology in literary production (Lyons, 2021, p. 13). This relates to the physical handling of the typewriter machine, the management of paper, and the interrelations between creative processes and the choice of writing technologies.

Lastly, the case study contributes to a reconceptualization of sheets of paper as 3D objects in the research of documents from the typewriter age. Projects like ARCHiOx (2022/2023), which employs PS to 'bring to life relief surfaces of some of the Bodleian's most celebrated artefacts' (Anon, 2022), demonstrate how computer vision is increasingly used to explore the surface topography of archival collection items.[10] At the same time, that project's 2.5D digitization of the late medieval Gough map, a seventeenth-century Rembrandt portrait, and eighteenth-century copperplate prints evidences a focus on older carriers of text and image. Our case study, however, has pioneered PS in the context of twentieth-century literature. Thus, whereas the three-dimensionality of older archival materials is already more widely acknowledged and researched, standard edition technologies and methods still treat newer literary documents as 2D. This study demonstrates that, also in the case of near-flat media, 3D features must be regarded and treated as constitutive parts of these cultural artefacts, which need to be preserved in conservation, archiving, reproduction, and exhibition contexts. Contributing to re-thinking sheets of paper as 3D objects whose surfaces record the physical traces of creative writing, computer vision makes a vital intervention in a field of research that, in the past two decades, has turned its attention to the material conditions and contexts of literary production.

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Author contributions

Simon Brenner (Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing—original draft, and Writing—review & editing), Timo Frühwirth (Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Writing—original draft, and Writing—review & editing), and Sandra Mayer (Conceptualization, Formal analysis, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing—original draft, and Writing—review & editing)

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Notes

1. Specifically focusing on the use of the typewriter in twentieth-century literary production, the recent work by Lyons (2021) and Fink (2022) is particularly pertinent to this case study.
2. We are aware that the reconstructed texts in question might have never been meant for publication. However, we want to demonstrate that, beyond the specific case study treated in this article, the technological and methodological approach taken here is capable of fundamentally advancing research on the material aspects of literary production in the context of the typewriter age. The authors have obtained the permission of The Estate of W. H. Auden to reproduce these hitherto unpublished literary texts.
3. Campe distinguishes the term 'writing scene' as the 'reality of the production of writing' from that of 'scene of writing' as the (e.g. literary) 'reflection on a writing scene' (Campe, 2021, pp. 1118, 1119).
4. In an educational resource from as late as 1990, the author advises the standard usage of backing sheets: 'Always type using a backing sheet to protect the platen or roller on the typewriter. Backing sheets are commercially available and are often made of very thin card. If you do not have a commercially produced backing sheet use a sheet of good quality typing paper behind your top copy' (Bailey, 1990, p. ix).
5. Another forensic method of investigating indented impressions, electrostatic detection, is not suitable for our purposes as it is applicable only in cases where impressions were created by means of handwriting—most probably because the electrostatic disruption that can be detected by means of this method depends on the lateral movement of the pen (Allen, 2015, pp. 201–202).
6. See, for instance, the application of raking light to document flat media by the Conservation Division at the Library of Congress (Edwards and Oey, 2018, Section 6).
7. The guidelines of the US Federal Agencies Digital Guidelines Initiative and the Dutch-based Metamorfoze initiative are among the internationally recognized standards of image digitization in the field of cultural heritage.
8. The image data set is openly accessible via https://doi.org/10.5281/zenodo.7706092. All source images will be made openly available through the Austrian Academy of Sciences' ARCHE long-term repository (https://arche.acdh.oeaw.ac.at) at the end of the project's duration in mid-2024.
9. The TEI-XML transcription is openly available via https://doi.org/10.5281/zenodo.7290753.
10. See also, for example, Endres (2019) for the application of Reflectance Transformation Imaging in the field of heritage and conservation studies.

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