Visualizing a Series: Aggregate Compositional Analysis of Botticelli's *Commedia*

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Abstract

Applying digital methods as inputs to an interpretive process, I expose compositional motifs within Sandro Botticelli's momentous *Divina Commedia* codex that depart from canonical manuscript illustrations. I then situate these visual findings within Quattrocento literary and artistic theory, arguing that Botticelli manipulated his compositional structures to harmonize with the humanist Cristoforo Landino's interpretation of the *Commedia* as an allegory for the soul's ascension from "disorder" to "order". By leafing through the pages of Botticelli's manuscript and perceiving the striking structure and style of the illustrations, the observer could experience the incremental progress of Dante the Pilgrim's soul — and perhaps the viewer's own — through the different stages of hell to paradise. Ultimately, I reflect on the implications of digital methodologies within art history, and how these techniques may enrich or even challenge traditional modes of "seeing" works of art.

Introduction

Sandro Botticelli's fifteenth-century drawings of Dante Alighieri's *Divina Commedia* are an art-historical puzzle. Throughout a lavish codex, the artist widely varies his mode of representation while chronicling Dante the Pilgrim's epic journey through the afterlife's three realms — *Inferno*, *Purgatorio*, and *Paradiso*. Although Botticelli doubtless illustrated all one hundred cantos (narrative units best understood as "little songs") of Dante's epic, only ninety-two folios from the series are extant.[1] Nevertheless, the surviving drawings confound. Each canticle of Botticelli's series (to use Dante's poetic unit for a realm of hell, comprising thirty-three cantos) seemingly derives from distinct compositional principles that depart from centuries of manuscript illustration.

[1]

Somehow, the unusual and innovative characteristics of Botticelli's codex must be indebted to Florence's swirling discourse around Dante's *Commedia*. Botticelli, as an early favorite of the Medici family, was raised within the cradle of Florentine humanism. Together with the learned academics, Marsilio Ficino, Politian, and Cristoforo Landino, the artist participated in the late Quattrocento explosion of vernacular culture and discourse. Indeed, as will be discussed later, Botticelli often reinterpreted textual sources through his compositions and iconography. Given this context, Botticelli's *Commedia* series must not plainly illustrate a narrative but instead, with tremendous originality and subtlety, give artistic expression to a poetic invention. However, what precisely this invention entails, and which humanist thinkers Botticelli called upon, remains to be treated.

[2]

Most scholars, while acknowledging the codex's unusual deviations from canonical *Commedia* manuscripts and Botticelli's close ties to literary circles, have refrained from identifying cohesive compositional patterns across the many drawings.[2] Indeed, traditional visual analysis alone — long a cornerstone of the art historian's toolkit — struggles to address such a multitude of images. As a result, researchers have largely demurred from addressing the work's totality, opting instead to focus on specific images or canticles alone. Yet novel observations on the *Commedia* must arise not from a biased selection of cantos, but rather from the entirety of Botticelli's ambitious project. To fully understand Botticelli's work and artistic intent, we must develop a new way of viewing that can decipher patterns and relationships across the *Commedia*'s breadth, not just its individual parts.

[3]

Recent literature reinforces the need to treat the *Commedia* series as a whole object. Sharifa Turab Lookman demonstrates, for example, that Botticelli did not execute the illustrations in the order suggested by Dante's narrative, as had long been accepted [Lookman 2017].[3] By piecing together ink marks and compass traces, Lookman discerned several "sets" of folios that Botticelli worked simultaneously. Each of the sets of related folios that Lookman identified concentrated not on a single canticle, but instead involved sheets from *Inferno*, *Purgatorio*, and *Paradiso*. Therefore, Lookman persuasively argues, Botticelli conceived of the *Commedia* as a unified whole, not as single folios or even clusters of drawings. Conclusions must then be drawn not merely across *cantos*, but also across *canticles*.[4]

This paper proposes a methodological innovation in the field of art history by applying digital techniques to elucidate the compositional complexities within Botticelli's *Commedia*. By correlating these stylistic choices with Quattrocento literary theory, the current study not only provides a novel interpretation of Botticelli's *Commedia* but also sets forth a procedure for digital visualization as a tool to analyze large corpora of works.

Supported with observations and visualizations drawn from all ninety-two extant folios, I argue that the manuscript's varying modes of representation can be understood as a pictorial expansion of the humanist Cristoforo Landino's prestigious 1481 Dante commentary. According to Landino, Dante the Pilgrim's soul experiences cacophonous disorder within *Inferno*, incremental organization within *Purgatorio*, and sublime unity within *Paradiso*. In kind, Botticelli adjusts his organizational schema for each canticle so that it appears to harmonize with Landino's corresponding allegory — figures are strewn across the page in *Inferno*, organized by some centripetal force in *Purgatorio*, and condensed into an ethereal whole in *Paradiso*.[5] By leafing through the pages and perceiving the striking structure and style of the illustrations, the observer could experience the incremental progress of Dante the Pilgrim's soul — and perhaps his own — through the different stages of hell to paradise.

Digital Visualization Techniques as an Input to an Interpretive Process

One of my central claims is that Botticelli, unlike earlier *Commedia* illustrators, altered his mode of representation to correspond with the central themes of each canticle. More specifically, I posit that the series exhibits a deliberate compositional arc — from disorder to unity — that was unprecedented within the canon of *Commedia* illustrations. To augment traditional visual interpretation, I adopt a two-part digital approach: first, I use digital visualization of the canticles on the aggregate to expose recurring patterns; and second, I employ descriptive statistics to make concrete how Botticelli's compositions differed from preceding editions.[6] These computational methodologies offer an innovative lens for "seeing", bringing into sharp focus patterns across the work's breadth. Then, I marry the scientific and the qualitative by drawing upon historical sources and suggest an explanation for the phenomena surfaced in the data.

Paging through the manuscript, Botticelli's viewers intuitively experience the differing modes of representation. Within *Inferno XXXIII*, for instance, scientific perspective and chronological narrative are cast aside for a tumult of episodes and vanishing points (Figure 1). Dante's sinners sequester themselves into distinct paratactic spaces, and all attempts to glean the logic of the patchwork quilt of flesh and agony leave the viewer frustrated and unsatisfied.

Figure 1. Sandro Botticelli, *Inferno XXXIII*, c. 1481-90. Ink and metal point on parchment, Kupferstichakbinett, Berlin.

Yet a few cantos later, the cacophonous discord of *Inferno* gives way to cohesion and consonance within *Purgatorio*. Take *Purgatorio XIII*: assembled in symmetric groups of two and three, Botticelli's penitents huddle together for comfort and warmth (Figure 2). Each pyramidal cluster emanates stability and solidarity rather than disarray.

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Figure 2. Sandro Botticelli, *Purgatorio XIII*. Ink and metal point on parchment. Kupferstichakbinett, Berlin

At last, Botticelli's *Paradiso* arrives with the reduction of structural principles to an ineffable simplicity characteristic of Dante's *Earthly Paradise*, as evident within *Paradiso IX*. Only two elegant figures — Dante and Beatrice — grace the page, at once distinct yet harmonious, engaged in an intricate dance about the central axis. Botticelli presents not only concord but also a simultaneous expression of intangibility, where either figure threatens to dissolve into the vellum's vast expanse (Figure 3).

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Figure 3. Sandro Botticelli, *Paradiso IX*, c. 1481–90. Ink and metal point on parchment. Kupferstichkabinett, Berlin

But a single illustration from each canticle cannot adequately represent Botticelli's momentous series, nor can three hand-picked examples mitigate confirmation bias.[7] Such limitations are inescapable when analyzing three canticles with thirty-three illustrations each.

Within textual disciplines, scholars have embraced computational analysis tools that measure word frequency patterns to overcome similar challenges, facilitating a new way to read large text bodies. These software packages serve as an adjunct to traditional close reading, illuminating intricate patterns – such as word usage, psychological tendencies, and language choices – that might otherwise evade human detection. [8] Borrowing from this methodology, although we cannot directly compare so many drawings, we can make sense of a much smaller selection of visualizations that aggregate the compositional structure of the larger group, supporting a qualitatively different kind of insight. A challenge, though, remains: how to represent the arrangement of forms within each canticle's thirty-three drawings *at once*, effectively creating a visual equivalent of a word frequency map?

Statistics offers one possible interpretative technique: heat maps. At their simplest, heat maps elucidate the spatial clustering of phenomena, rendering once inscrutable data sets comprehensible at a glance. The term "heat" refers not to physical temperature, but instead to the density of the entity under consideration, where "red" typically indicates greatest concentration. Since heat maps convert longitudinal point data into a single interpolated surface, they wield tremendous — as yet unrealized — potential as compositional visualization tools for art history. Namely, in the case of a *Commedia* manuscript, by labeling the *x*, *y* coordinates of all figures (sinners, devils, penitents, etc.) throughout a given canticle, we can construct a single heat map that reveals patterns in how Botticelli tended to construct his compositions.

To expedite the tedious procedure of labeling figure locations (as there are more than one thousand across Botticelli's series alone, to say nothing of the comparative materials that must be considered as well), I designed a web application. In essence, this application recorded the coordinates of any point clicked with the mouse, allowing for the rapid and accurate collection of figure locations. I conducted this procedure not only for Botticelli's codex, but also for two Tuscan codices that were in all likelihood familiar to Botticelli, and which he drew upon for inspiration: the Bodleian Libraries' Trecento manuscript, MS Holkham Misc. 48, and the British Library's Quattrocento manuscript, MS Yates Thompson 36. [9] If heat map analysis of Botticelli's manuscript, but not these two canonical works (which typify the preceding illumination practice), demonstrate differing modes of representation across the series, I could then support my compositional argument with some confidence.[10]

The heat map analysis revealed no structural differences between the compositions illustrating the canticles in either MS Holkham Misc. 48 or MS Yates Thompson 36 (Figure 4, Figure 5). From the visualizations, the spread of figures is relatively similar, as are the centralized regions of focus. While some variation persists — due in part to Dante the Pilgrim's dynamic environment — a single compositional paradigm of linear organization prevails. No hierarchy of form emerges, as all figures appear equal.
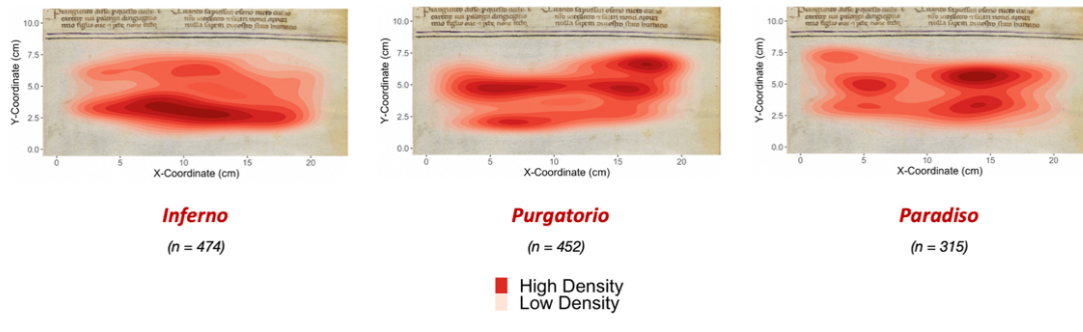
Figure 4. Density maps of the figures throughout each canticle for MS Holkham Misc. 48. Darker red indicates greater figural density.
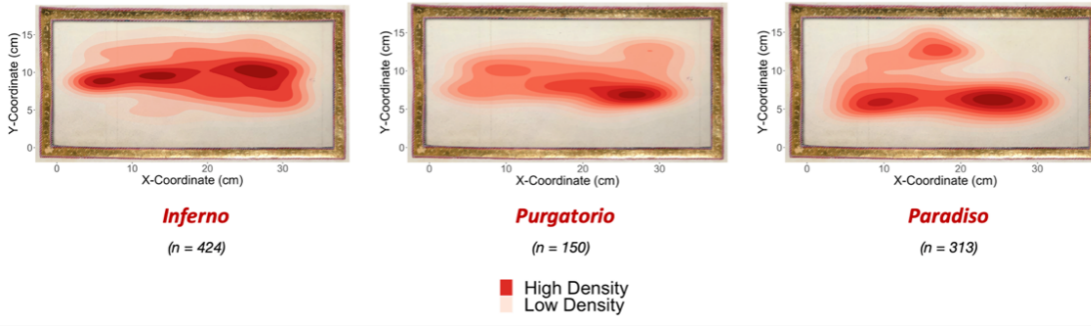
Figure 5. Density maps of the figures throughout each canticle for Yates Thompson MS 36. Darker red indicates great figure density.

Analysis of the heat maps of Botticelli's *Inferno*, *Purgatorio*, and *Paradiso* illustrations, in contrast, expose how each canticle adheres to a distinct mode of representation (Figure 6). Take for example the *Inferno* compositions: the figures are spread across the page, with many banished to the fringes — a fitting locale for those souls who in life strayed from the righteous path. Returning to Botticelli's *Inferno XXXIII*, we find figures are juxtaposed without subordination; no social hierarchy or formal relationships arise from the diffuse chaos (Figure 1). Sinners are literally hewn in two at the edges of the parchment. The viewer's eye, desperate for an aesthetic focus, wanders across the page. The *Purgatorio* heatmap, meanwhile, reveals an underlying centripetal organization that is consistent with the introduction of compositional principles visible within *Purgatorio XIII* (Figure 2). No longer are figures clustered near the edges in isolation and distress. Instead, the central locations become the most prominent, radiating balance and harmony. And

finally, the *Paradiso* heatmap illustrates the reduction of chaotic structure to a simple unity, as seen in *Paradiso IX* (Figure 3). Dante and Beatrice float untethered through the ocean of parchment as if engaged in a cosmic waltz; unconcerned with earthly troubles, they ascend towards the Empyrean.
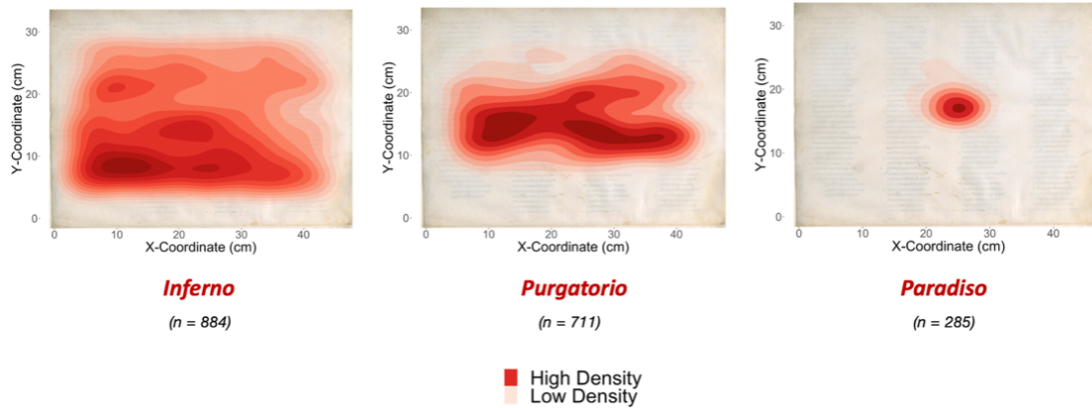
Figure 6. Density maps of the figures throughout each canticle for Botticelli's *Commedia* drawings. Darker red indicates great figure density.

The use of such heatmaps within art historical analysis, however, has limitations. First, a single heavily populated folio could exercise outsized influence on the final, aggregated visualization. The resultant chart would then not necessarily represent an "average" composition, but instead a "weighted" one. Second, heat maps require arbitrary input parameters, like the raster cell size, which refers to the extent of the area to group together into a single color. At one extreme, every point in a composition could be contained within the same cell, obscuring any patterns. At the other extreme, the visualization could dissolve into an unintelligible mass of points that exhibit few trends. Third, the comparison of heat maps is inherently qualitative. In other words, we can subjectively examine the three visuals and proclaim that they exhibit stark differences, but how can we be certain such irregularities did not arise by chance?

While heat maps give obvious visual clues to patterns across the series, to move from general observation to quantification, we must incorporate statistical tests as well. Scholars from related fields have successfully used similar techniques to tackle humanistic research questions. For instance, archaeologists applied hypothesis tests to evaluate whether social status or sex influenced burial types within the Parthian Empire, ultimately concluding that no statistically significant difference existed [Eghdami et al. 2023]. Drawing a parallel again to Botticelli's drawings, we must find a way to *quantify* each canticle's thematic variations, and then can conduct hypothesis tests to uncover and examine any trends.

How, indeed, can we measure Botticelli's differing modes of representation? No doubt, convolutional and non-parametric methods offer potential solutions. Weinstein et al. raise one possibility with their algorithmic treatment of Paul Cézanne's *Bathers* [Weinstein, Voss and Soll 2019]. By repurposing a dendrology computer application to identify axial symmetry and golden ratios within Cézanne's *Bathers* series, the authors discovered that the works' compositions — previously characterized as "awkward" — in fact conform to harmonious mathematical proportions. However, such an algorithm would prove less fruitful when applied to Botticelli's *Commedia*, as the *Paradiso* illustrations most often exhibit only two figures, and the diffuse confusion within *Inferno* resists structural analysis.[11] The authors' adapted dendrology technique, while adept at locating compositional *harmony*, fails when confronted with unmoored figures and assiduously devised *disharmony*. A more parsimonious approach would capture within a statistic the spread of the figures from the center. As the Dante scholar Rachel Jacoff remarks, "For Dante, sin is a violation of community" [Jacoff 2018]. Indeed, the presence of a cohesive community most distinguishes Botticelli's three canticles; accordingly, the physical (and therefore emotional) distance between figures suffices as an adequate measure.

And so, to analyze the *Commedia* illustrations through these methods, I took the centroid — the geometric center of a shape — as the "middle" of a composition (Appendix Figure 10). To quantify the spread of the forms within a given

canto, I computed the mean distance from the topological centroid to each figure (overarching procedure illustrated in Figure 11 in the Appendix; means for each canticle found in Appendix Figure 10). Next, to evaluate whether the mean spread of figures differed significantly by canticle, I performed a one-way analysis of variance (ANOVA), a standard test for statistical significance when comparing three or more groups (see Appendix for discussion of statistical techniques). [12] In all cases, statistics validated the trends first observed in the heat maps: for both MS Holkham Misc. 48 and MS Yates Thompson 36, the analysis revealed no significant compositional variations across canticles ($p = 0.751$ and $p = 0.279$, respectively),[13] while for Botticelli's manuscript, the results indicated that the canticles are compositionally distinct ($p = 2.2 * 10\text{-}16$).[14]

What is more, close study of the series (conducted both on the drawings in the flesh and through high-quality visual reproductions) reveals that Botticelli adjusted more than his mode of representation: his drawing style exhibits stunning variation by canticle as well. Within *Inferno*, the artist sketched frantic, heavy lines in dark ink, evoking the chaotic energy endemic to Dante's hell. Consider the depiction of Dante the Pilgrim's figure within *Inferno XXXIII* (Figure 7).[15] Gestural lines start, stutter, and cease, conveying form but not volume. The strokes' weight lends Dante's figure material presence, yet their angularity insists that he exists outside of the human world. Botticelli's representation of the two wayfarers in *Purgatorio XIII*, meanwhile, typifies the greater sense of naturalism present within the second canticle's drawings (Figure 7). Sketched in a mixture of light and dark ink with significant metal point underdrawings, Botticelli's strokes are confident, deliberate, and measured. We here witness the series at its most tangible: the figures of Dante and Virgil threaten to wander off the page and into the profane world. The pen strokes of *Paradiso*, on the other hand, are thin and hesitant, with no signs of the dark ink that suffused the earlier canticles. As a demonstration, follow the line suggesting the outer fold of Beatrice's diaphanous drapery within *Paradiso IX* (circled in red in Figure 7). The stroke slopes gently downward, swerves abruptly, and terminates just short of Beatrice's sleeve. A second mark overlaps the first's lower section, but also ceases inexplicably. This is not an anomaly — Beatrice's whole ensemble consists not of continuous strokes, but instead a precarious assemblage of disembodied lines, each drifting unmoored from its neighbors. The artist's drawing mode thus mimics the evanescent nature of his subject. The wayfarers are both present and absent, flitting between the ordinary and the transcendental.[16]

| Detail from *Inferno XXXIII* | Detail from *Purgatorio XIII* | Detail from *Paradiso IX* |

Figure 7. Details of Botticelli's differing drawing style within *Inferno XXXIII*, *Purgatorio XIII*, and *Paradiso IX*.

Such a process — first clarifying a pattern through digital art-history methods, and then augmenting that discovery through close visual analysis — illustrates the symbiotic relationship between the scientific and the visual. Even so, the utility of computational techniques within art history remains limited. As Pamela Fletcher explains, digital tools function as "machines for thinking with, rather than replacements for thinking" [Fletcher 2015]. All too often, researchers indiscriminately apply scientific approaches to art history and publish their interpretations of the results, unconsciously presupposing an unchangeable context of seeing. In other words, the original way a work was viewed — what the art historian Michael Baxandall refers to as the "period eye", cultivated through exhaustive analysis of historical sources — can differ dramatically from modern perspectives and so must be considered alongside the data [Baxandall 1964].[17] Thus, although digital technologies make a formidable addition to the modern art historian's methodological toolset, they

merely complement, and cannot substitute for, deep knowledge and scholarly investigation. Applying these considerations to the current study, while heatmaps and statistical analysis make clear that Botticelli varied his mode of representation by canticle, movement from observation to interpretation necessitates the introduction of Quattrocento literary and artistic theory.

Interpreting Botticelli's Thematic Patterns within a Quattrocento Context

Earlier *Commedia* illuminators were bound by a textual primacy that restricted and overshadowed their illustrations. Scribes would leave gaps in the verse, and often provide written instructions to the illuminator as well, thereby dictating the decision of *where* and often even *how* an artist could work.[18] But after Nicholas Jenson's 1470 Roman font fixed humanist handwriting in type of an unmatchable beauty and regularity, attention shifted to pictorial interpretation of the text, as with illustration the craftsman could still far exceed the printer.[19] Botticelli's codex, as an explosion of the book, accentuates this cultural inversion: he banished the text to the rough verso, and instead privileged the images on the smooth recto.[20] If oriented horizontally, and bound in a deluxe codex, the viewer would first encounter the drawings, and then the text. To be sure, Botticelli incorporated elements of previous Dante manuscripts into his designs. But of course, Botticelli was also well acquainted with monumental panel painting, and inspired by the Renaissance spirit of experimentation. Indeed, Botticelli models his topography of *Inferno* after Domenico di Michelino's c. 1465 massive panel painting *Dante Reading from the Divine Comedy* in the north aisle of the Florence Cathedral, where readings from the *Commedia* had been held since at least 1432 [Rowlands 2003].[21] Significantly, the aspect ratio (the ratio between the width and the height) of Botticelli's *Commedia* codex is almost identical to that of his *Primavera* and *Birth of Venus* panel paintings.[22] Hence, while translating between media, Botticelli suffused his work with remnants of his storied Florentine panels to emancipate image from text and inflect his drawings with Renaissance innovations.[23]

Further, following the Renaissance ethos that "a painting is indeed nothing else but a wordless poem", scholarship on Botticelli's panel paintings demonstrates how the artist's compositions and iconography innovatively reinterpret classical sources.[24] Stanley Meltzoff, for instance, proposes that Politian was the rhetor (or architect) for Botticelli's c. 1494-95 panel painting, *Calumny of Apelles*, advising the artist on which moralizing vignettes to include, and how they ought to be represented, based on precedent from classical sources (Figure 8; [Meltzoff 1987]). The sixty-four visible *rilievo schiacciato* reliefs, Meltzoff maintains, weave an intricate moral argument for the necessity of beauty and eloquence within the liberal arts.[25] Ernst Gombrich similarly relates Botticelli's *Primavera* (c. 1477–1482) to the philosopher Ficino's Neoplatonism, suggesting that the artist intended the work to impart a didactic lesson to its rebellious patron, Lorenzo di Pierfrancesco de' Medici (Figure 9; [Gombrich 1945]). Charles Dempsey expands on Gombrich's thesis, arguing that in the *Primavera*, we witness the two great cultures of Italy — ancient Latin and vernacular Tuscan — brought together in indissoluble union. "Botticelli's painting", Dempsey writes, "is informed by such a fine poetic instinct, combined with philological rigor and tact so exquisitely deployed, that it produces its own aesthetic response" [Dempsey 1992, 30].

Figure 8. Sandro Botticelli, *Calumny of Apelles*, 1494-95. Tempera on panel. Florence, Uffizi.

Figure 9. Sandro Botticelli, *Primavera*, 1477–1482. Tempera on panel. Florence, Uffizi.

It is reasonable to speculate, then, that Botticelli's *Commedia* series also manifests contemporary poetic and literary discourse. Taking Dante as his theme, Botticelli suffuses his *Commedia* manuscript with the new Florentine culture birthed from Lorenzo de' Medici and amplified by the latter's coterie of poets and philosophers. If Politian was the architect of Botticelli's *Calumny of Apelles*, and Ficino instrumental for the *Primavera*, might we hypothesize a rhetor for the *Commedia* series?

The likely candidate here is the humanist Cristoforo Landino, whose influential Dante commentary and text, *Comento sopra la Comedia*, was printed in Florence in 1481.[26] Botticelli apparently pored over the *Comento* with great attention. The artist's own *Calumny* composition derives from an ekphrasis found within Landino's text, and the edition was even published alongside preliminary engravings of Botticelli's series.[27] Therefore, Landino's commentary presents a contextually relevant parallel to Botticelli's drawings that can augment computational findings.[28]

Study of the *Comento* alongside the *Commedia* illustrations reveals how Botticelli develops a pictorial expansion of Landino's work that is every bit as innovative and nuanced as its printed counterpart. According to Landino, Dante's *Commedia* presents a nuanced allegory for the soul's ascension from sinful "disorder" to divine "order". Gradually, Dante the Pilgrim purges himself of vice and elevates his spirit from profane temptation ("disorder") to sacred grace ("order"). Misalignment of body and soul reigns in *Inferno*, Landino maintains, while divine governance facilitates penance in *Purgatorio* (the most human of domains), and all mundane structure dissolves under the ineffable radiance of *Paradiso*. [29] Landino's incremental organization of the soul relates strikingly to Botticelli's calculated variation of his style and mode of representation in his *Commedia*. Indeed, the heat maps and statistical analysis suggest a familiar story: diffuse

cacophony within *Inferno*, where members sequester themselves into discrete paratactic spaces; meticulous harmony within *Purgatorio*, where social organization and divine forces guide both Botticelli's compositions and Dante's penitents; and unity within *Paradiso*, where earthly principles of structure and verse give way to a sublime simplicity. But to say that Botticelli simply adapts Landino's interpretations is to dramatically understate the innovative and effective properties of the images. While Botticelli finds inspiration in Landino's allegorical treatment of Dante, his ensuing explosion of the illuminated manuscript tradition is entirely novel and unprecedented.

Conclusion

Botticelli's *Commedia* series, at once literary exegesis and synoptic illustration, occupies an unmatched position within Dante's illuminated tradition. Later cycles, including those of Salvador Dalí, William Blake, and Gustave Doré, adapt Dante's text with their own unique interpretations; however, they all build from Botticelli's model by elevating image over verse and departing from faithful representation to find visual equivalents of the human phenomena that Dante the Pilgrim experiences.

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This paper applied an interdisciplinary approach involving both traditional visual analysis and novel statistical methods to demonstrate that Botticelli deviated from canonical manuscripts by adjusting his mode of representation to the canticle at hand. Botticelli's varying compositions, I propose, can be understood through study of the series alongside Landino's *Comento*, presenting Botticelli's manuscript as a pictorial expansion of Landino's exhaustive commentary. Digital tools thus enrich formal visual analysis, providing a materially distinct way of "seeing" a work of art. We can react to the emotive depth of Botticelli's drawings, marvel at the master's treatment of line and form, and then, empowered by digital methodologies, discuss cross-series compositional trends.

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However, the possible applications of digital techniques to art history, and even to Botticelli's *Commento*, extend far beyond compositional analysis. Future investigations could, for example, quantify Botticelli's handling of strokes, applying edge detection or morphological operators as interpretive tools to describe and measure the line's comparative weight, curvature, and decisiveness. With recent advancements in machine learning, scholars could even apply digital techniques to reinforce the connection between Landino's *Comento* and Botticelli's series. We have used descriptive statistics to quantify *visual* parataxis (disharmony) within the drawings; we could similarly apply large language models to measure *textual* parataxis within Landino's work and relate the two. Indeed, with the increasing number of digital tools available to scholars, similar analyses will no doubt unearth previously unseen patterns across all disciplines of the humanities, inviting careful qualitative research and expert interpretation.

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Acknowledgements
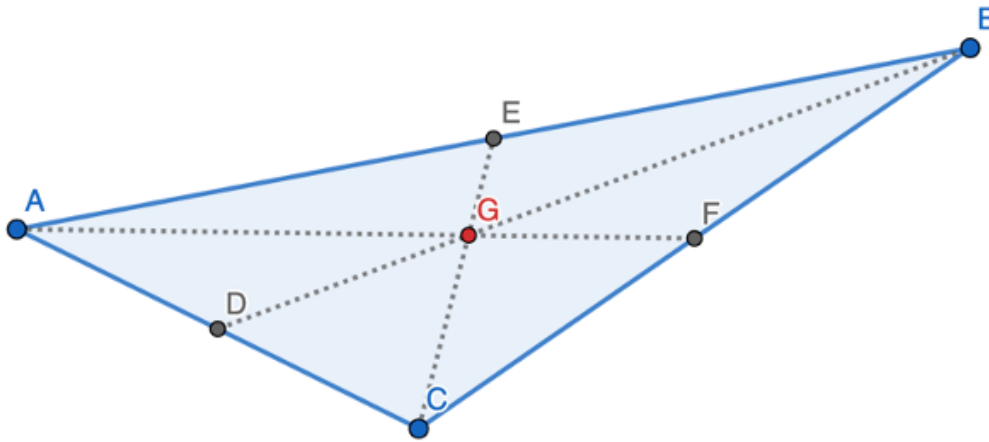
Appendix

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Figure 10. Illustration of the geometric centroid (labeled "G") for the triangle ABC. Mathematically, the centroid is the point where the medians intersect; or, equivalently, the arithmetic mean position of all points within a figure.
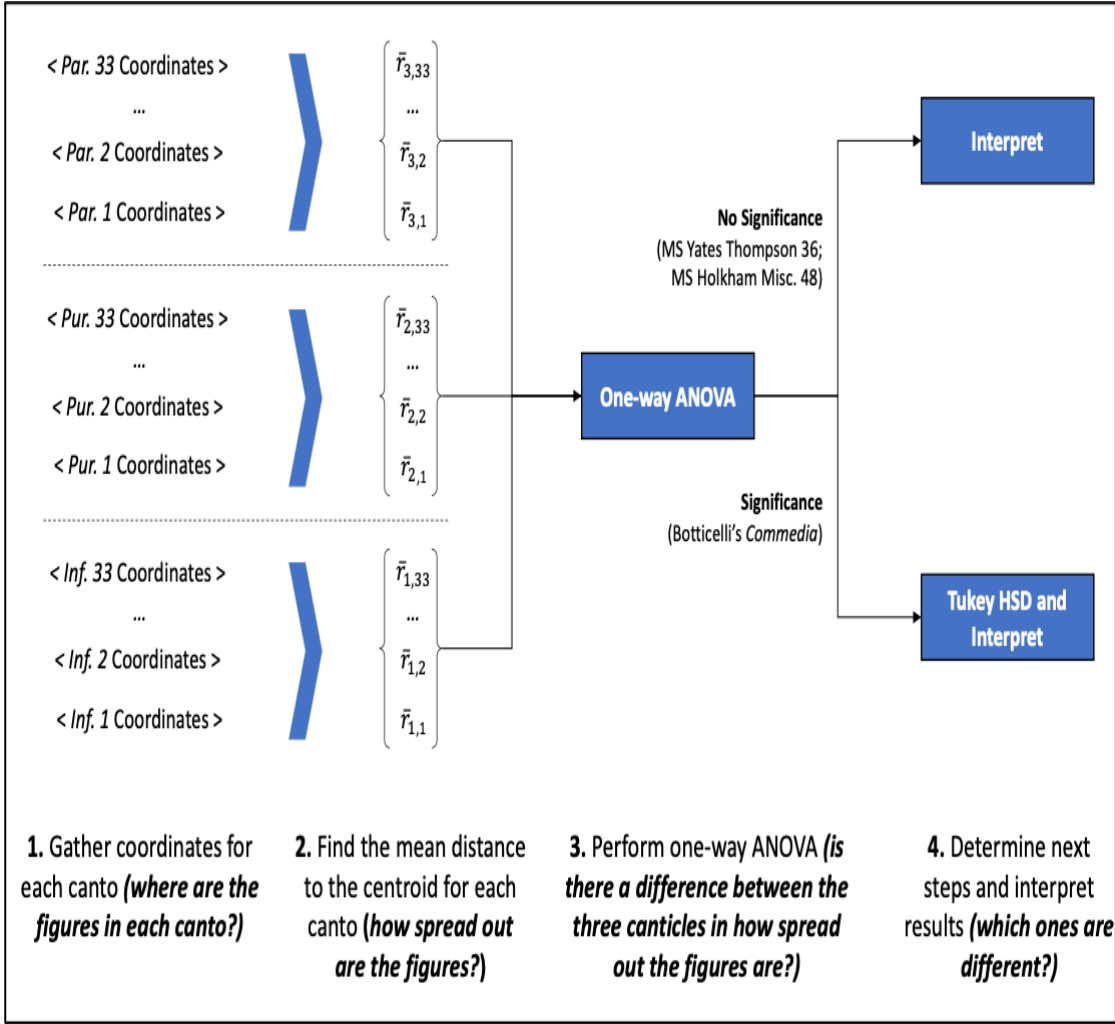

Figure 11. Flowchart for statistical analysis of illuminated manuscript illustrations. Describes the step-by-step process that each manuscript underwent in order to determine whether the compositions within *Inferno*, *Purgatorio*, and *Paradiso* differed statistically.

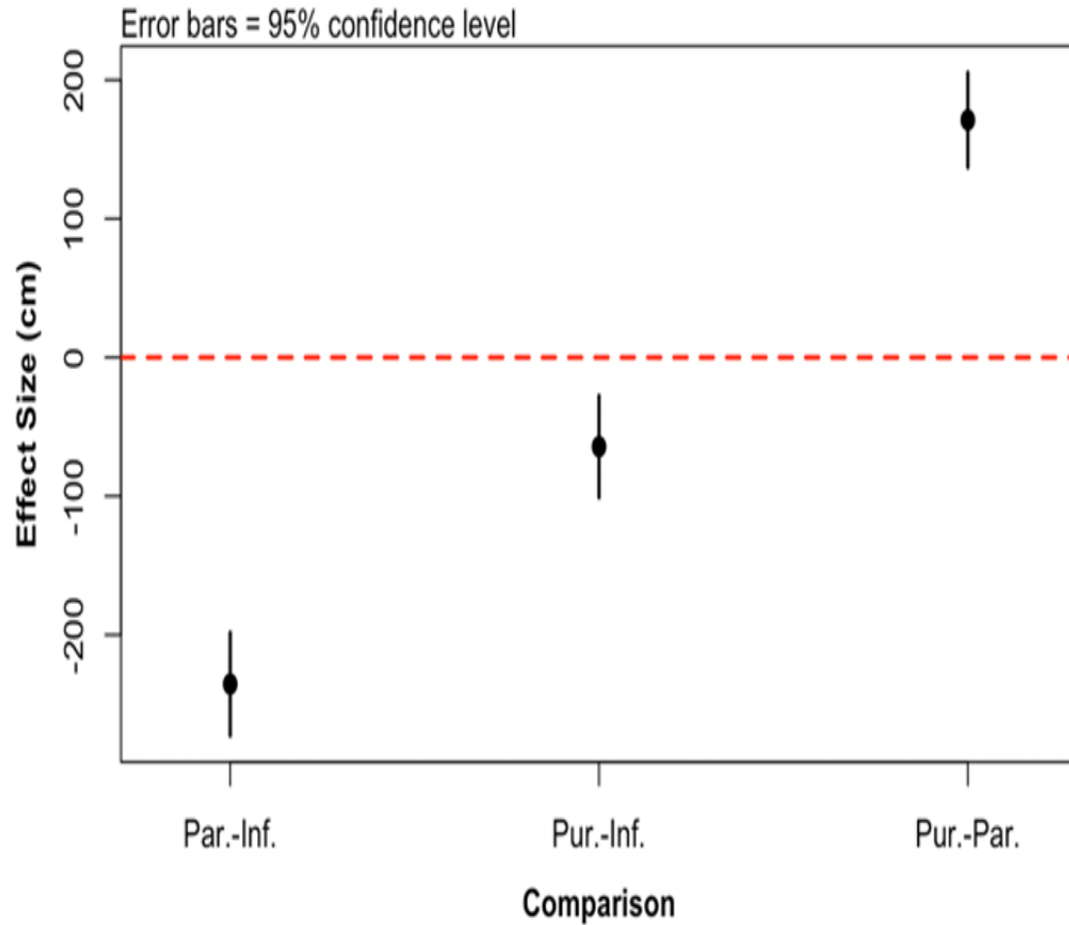## Post-hoc Tukey HSD Analysis for Botticelli's Drawings

Figure 12. Graphical representation of the post-hoc Tukey HSD test performed on Botticelli's *Commedia* series. The boundaries indicate 95% confidence intervals — tellingly, none of them cover zero. The *p*-values for the combinations were all extremely small, allowing for rejection of the null hypothesis. Thus, the mean distance to the centroid differed significantly for all possible combinations.

	Inferno (cm)	*Purgatorio* (cm)	*Paradiso* (cm)
Holkham Misc. 48	4.55 (1.16)	4.30 (1.20)	4.88 (1.95)
Yates Thompson 36	7.42 (0.70)	7.41 (0.99)	7.02 (1.31)
Botticelli	12.4 (1.67)	10.1 (1.54)	4.03 (2.64)

Table 1. Data table of the mean distance to the centroid (standard deviation in parenthesis) for each canticle of the three manuscripts analyzed. Botticelli's manuscript, the data suggests, is the only one where the mean varies substantially.

	Degrees of Freedom	F value	P value
Holkham Misc. 48	2	0.2869	0.751
Yates Thompson 36	2	1.297	0.279
Botticelli	2	129.3	2.20 * 10–16

Table 2. One-way ANOVA analysis for each manuscript series analyzing the impact of the categorical variable canticle on the mean distance to the centroid. A significant effect was observed only for Botticelli's manuscript, whereas no others were significant at any level.

Statistical Techniques

One-way ANOVA

One-way ANOVA is a statistical test used to determine whether there are any statistically significant differences between the means of three or more independent groups. In our study, these groups are represented by Botticelli's three canticles: *Inferno*, *Purgatorio*, and *Paradiso*. In this case, the null hypothesis is that there is no significant difference between the means of the canticles, suggesting that Botticelli's compositional approach is consistent across the series. If the *p*-value is less than a predefined significance level (usually 0.05), we reject the null hypothesis in favor of the alternative: the canticles are compositionally distinct. One key limitation of ANOVA is that while it can detect differences between groups, it does not specify which groups are different. Another consideration is the assumption of normality and equal variances in the data, which if not met, may lead to erroneous conclusions.

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Post-hoc Fukey HST

To address the limitations of ANOVA, the post-hoc Fukey HST was applied as well. This test is designed to compare all possible pairs of means to ascertain which specific groups differ significantly. In our study, we compare *Purgatorio* vs. *Inferno*, *Paradiso* vs. *Inferno*, and *Paradiso* vs. *Purgatorio*. If a significant difference is found, it suggests that the mode of representation is significantly different between those canticles. The strength of the Fukey HST is that it controls the experiment-wide error rate, reducing the chance of making Type I errors (false positives). It's important to note that post-hoc tests, including Fukey HST, rely on the initial ANOVA to indicate that differences exist among groups. If the ANOVA is not significant, performing post-hoc tests is statistically inadvisable.

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Notes

[1] Medieval writers regularly employed the vernacular locution "canto", from the Latin "*cantus*", to reference songs and lyrical composition. However, Dante endows the term with a new sense — as each of the one hundred narrative units that compose his *Commedia*. Dante presents one introductory canto followed by three large narrative subsections, labeled "canticles", of thirty-three cantos each (*Inferno*, *Purgatorio*, and *Paradiso*). The overarching structure of the *Commedia*, then, follows the organization: 1 + 33 + 33 + 33 = 100 cantos [Lansing 2010, 139]. Of Botticelli's surviving illustrations, seven reside in the Biblioteca Apostolica Vaticana, while the remaining eighty-five vellum sheets entered Berlin's Kupferstichkabinett in 1882 from the Duke of Hamilton's collection.

[2] Hein-Thomas Schulze Altcappenberg, in his exhibition catalogue on the series, stresses Botticelli's enigmatic use of "an apparently outmoded narrative technique" coupled with "widely differing modes of representation" that depart from canonical Dante illustration [Schulze Altcappenberg 2000, 35]. Or, as Friedrich Lippmann describes: "[I]n *Inferno* and *Purgatorio* the compositions contain a great variety of small figures, whereas in *Paradiso* the scale is larger, and in many of the drawings, Dante and Beatrice appear alone" [Lippmann 1896, 18].

[3] Lippman first proposed that "Botticelli's designs were produced in the order suggested by the poem", a claim that was largely uncontested until recently [Lippmann 1896, 19].

[4] The close relationship between text and image within Botticelli's series further reinforces the utility of a digital art history approach. As medievalist Sonja Drimmer warned in an interview, we must resist the temptation to subordinate image to text by asking, "'How does the image reflect the author's text'", and instead inquire, " 'How does the author's text illuminate what we observe first in the image?'" [Drimmer 2019].

Making use of computational techniques helps alleviate the risk of imposing textual interpretations onto the drawings, as we first derive insights from the series as a whole, and then look to the historical sources to add vital context [Drimmer 2019].

[5] My proposal — that Botticelli adjusts his mode of representation to suit the canticle — finds literary precedent in Dante's notion of "*contrapasso*"; literally, Italian for "counter-suffering" (not to be confused with the ubiquitous art-historical term "*contrapposto*"). Within the *Commedia*, "*contrapasso*" refers to the balancing of the sin and the punishment. That is, the retribution reflects the crime; or, more precisely, the *contrapasso* exposes the sin's horror through a grotesque perversion. *Inferno XX* provides a quintessential example. The sorcerers, astrologers, and misleading prophets must wander across the tundra with heads "twisted — their faces looked down on their backs; / they had to move ahead by moving backwards; / they never saw what was ahead of them" (*Inf.* 20.13–15). Fittingly, Dante condemns those who in life falsely claimed prescience to perpetually look backward at their ill-conceived crimes, not forward to the future. I suggest that Botticelli's *Commedia* program is an artistic elaboration of Dante's literary *contrapasso*: just as Dante matches the punishment to the sin, so too does Botticelli match the composition to the rules and aesthetics of the corresponding canticle. For the translation of *Inferno XX*, see Mark Musa's 1996 edition [Alighieri 1996].

[6] Recent scholars have fruitfully employed similar digital methods to illuminate patterns across large collections of works. For instance, Alexander Brey recorded the features of an extensive Quran manuscript within a digital database, and conducted principal component analysis (PCA) on the resultant data set, revealing subtle trends in the complex and varied sura heading decoration([Brey 2017].

[7] Within psychology, confirmation bias (colloquially "cherry-picking") refers to the tendency of researchers to search for and include only the examples that support their existing hypothesis. In the context of the *Commedia*, that would involve authors' selection, conscious or unconscious, of only the cantos that bolster their previously determined argument.

[8] A treatment of computation techniques within textual sources is given in [Argamon and Olsen 2009].

[9] According to a 1495–96 inventory, the Medici library alone boasted at least six sumptuously bound manuscripts of Dante's *Commedia* — all of which Botticelli would have had unrestricted access to, given his elevated position within the Medici circle. As such, Botticelli would have been eminently familiar with most extant Tuscan editions, and perhaps with several other models now lost. For the original inventory, see [Piccolomini 1874]. Scholars have also identified consistencies between Botticelli's codex and preceding models, further confirming the influence of canonical manuscripts. For an instructive treatment on the pictorial tradition of the *Commedia* and the illuminator's tradition of copyists, look to [Alexander 1992, 140].

[10] In general, Botticelli may have been exposed to three roughly chronological idioms of *Commedia* manuscripts. The categories are: first, those with miniatures interspersed among the text and numerous illustrations per canto; second, those with more extensive so-called marginal vignettes; and third, those with larger, full-width scenes executed above or below the text, including a more complete treatment of events. The second and third styles are typified in the current study with MS Holkham Misc. 48 and MS Yates Thompson 36, respectively, while the first style exhibits such minimal compositional variation that statistical analysis is unnecessary.

[11] A version of Weinstein et al.'s algorithm modified to detect and quantify violations of proportion rather than adherence to golden ratios, however, might allow novel insights into Botticelli's *Commedia* drawings.

[12] I am indebted to Amherst College's Professor of Statistics and Data Science, Nick Horton, for his advice regarding these statistical calculations.

[13] The large *p*-values found from the ANOVA analysis ($p = 0.751$ and $p = 0.279$, respectively) did not allow rejection of the null hypothesis that any discrepancies between canticles could be attributed to random noise (Appendix Table 2).

[14] More formally, the small *p*-value allowed rejection of the null and conclusion of the alternative hypothesis. One complication remains, however. Although the ANOVA confirms the presence of a statistical difference between the three groups, it does not identify which group(s) are different. I therefore conducted a post-hoc Fukey honestly significant test (HST), which compared all three options (*Purgatorio* vs. *Inferno*, *Paradiso* vs. *Inferno*, *Paradiso* vs. *Purgatorio*) and reported which differ significantly. For Botticelli's *Commedia* drawings, the post-hoc Fukey HST indicated that, indeed, all three combinations are significant to a high degree, and that each canticle thus operates within distinct compositional principles (Appendix Figure 12).

[15] For the drawing style of *Inferno*, and later for the other two canticles, I supply a single example to illustrate the stylistic trend. Of course, as discussed, a single folio from a set of thirty-three is not convincing evidence across the canticle. Further digital art history scholarship(perhaps employing image manipulation to isolate disconnected lines and heavy strokes, for example) is needed to explore how the trend holds across the work's totality.

[16] In *Paradiso I*, Dante admits, "I could not look for long, but my eyes saw / the sun enclosed in blazing sparks of light like molten iron as it pours from the fire" (*Par.* 1.58-1.60). Of course, how could Botticelli render in permanent, dark ink what Dante experienced as if squinting into the blinding sun?

[17] The perils of scientific approaches to art history without proper period context are perhaps most obviously manifest within recent studies of portraiture, as discussed by Yael Rice and Sonja Drimmer. As an example, Rice and Drimmer highlight a recent study on the Habsburg jaw. After an analysis of sixty-six Habsburg family portraits, the study's authors conclude that the consistent presence of large jaws evidences inbreeding. Yet, as Rice and Drimmer astutely note, within dynastic portraiture, portrayal of the sitter with a feature distinctive to one of the family's ancestors helps reinforce the royal lineage. Indeed, the painter's aim was to legitimize, not accurately depict (although as Rice and Drimmer emphasize the notion of "accuracy" itself varies across time periods and geographies), his subject. By assuming that likeness reflects reality, the study's authors failed to incorporate their genres context, thereby introducing critical bias into their research ([Rice and Drimmer 2020].

[18] See especially [Alexander 1992, 39–42].

[19] Look to [Davies 1996, 48].

[20] In codicology (the study of manuscripts), each folio of parchment has two sides: the "verso" (back) and the "recto" (front). For vellum, the verso is the rough side of the parchment leaf, while the recto is smooth and more suited for detailed illustration. Indeed, the term recto derives from the Latin *rectum*, meaning "right" or "proper". Look to [Lyons 2011, 21]. It must be noted as well, however, that Botticelli's *Inferno I* is sketched on the verso, since the famous *Chart of Hell* occupies the recto. For a discussion of Botticelli's format, see [Schulze Altcappenberg 2000, 18].

[21] For a study of the topography of Botticelli's *Inferno*, refer to [Watts 1995].

[22] The aspect ratio of Botticelli's *Commedia* is 1.5:1, the same as that of the *Primavera* (1.5:1), and very close to that of the *Birth of Venus* (1.6:1). Canonical illuminated manuscripts, by contrast, have aspect ratios in the neighborhood of 0.6:1.

[23] Botticelli's *Commedia* can further be understood within the context of Florence's posthumous reclamation of Dante. Despite exiling the poet a mere century earlier, fifteenth-century Florentine aristocrats clamored for the reunification of Dante's body and his birthplace. In 1430, the humanist and statesman Leonardo Bruni petitioned for the return of Dante's remains from Ravenna (where he died in exile) to Florence. "This man's glory is such that he undoubtedly adds to the splendor and renown of our city", Bruni writes [Cachey 1995].

[24] The Italian humanist Bartolomeo Fazio then continues, in his Quattrocento treatise *De pictoribus*: "For truly almost equal attention is given by both to the invention and the arrangement of their work" (translation from [Baxandall 1964, 98]). More broadly, Horace's famous dictum — "Ut pictura poesis"; literally; "a picture is like a poem" — anchored much of the Renaissance's revived interest in rhetoric's visual manifestations (*Ars Poetica*, Line 361). For the given translation, see [Horace 1926, 480].

[25] Such a statement, Meltzoff continues, was needed given the ascetic friar Savonarola's sermons advocating that even Christian poetry and eloquence were mere pig swill, fit only for animal natures ([Meltzoff 1987, 86]. *Rilievo schiacciato* is a sculpting technique that allows for flattened reliefs to represent convincing spatial recession through optical illusion.

[26] For the full argument, summarized here, look to [Corley 2020].

[27] And yet, scholars have largely neglected Landino's commentary. As two thousand pages of Renaissance Tuscan, still untranslated into modern Italian or English, Landino's *Comento* is a formidable tome. Moreover, the most comprehensive secondary source on Landino's *Comento*, Bruce McNair's *Cristoforo Landino: His Work and Thought*, was published in 2019, and hence previously unavailable [McNair 2019]. Botticelli's adaption of Landino's *Calumny* ekphrasis is first advanced in [Dressen 2017].

[28] Implicit in my argument is that the target audience for Botticelli's *Commedia* drawings would be familiar with a whole host of humanist texts, including Landino's Florentine commentary. Typically, this assumption of such a privileged viewer would not stand. Margaret Miles, for example, emphasizes the need to "not focus on the associations and interpretation of a viewer who was culturally or educationally privileged in relation to most people in his culture" [Miles 1992, 28]. Undeniably, I am suggesting just that! But, because we know that the erudite aristocrat Lorenzo di Pierfrancesco de' Medici commissioned Botticelli's drawings for, at least initially, his personal collection, such an assumption holds. For a summary of the scholarship on the drawings' patronage, look to [Schulze Altcappenberg 2000, 21].

[29] Summarized from original primary-source study of Landino's text alongside Bruce McNair's instructive monograph [McNair 2019].

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