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Application of Face Encoding to Art Investigations

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ABSTRACT

Through the millennia, one of the primary goals of the art of painting has been an optical depiction of the scenes of the three-dimensional world that form our visual experience. A key role of paintings has been to depict faces in portraiture, conveying the identity of figures of contemporary and historical interest. The effective recognition of such figures requires accurate interpretation of the 3D configuration of the facial features, which is presently a largely subjective art, given the variety of poses employed. A quantitative technique for the analysis of facial expression and 3D facial configuration from the 2D artworks, is applied to the question of how Leonardo da Vinci looked as a young man. There are no accepted portraits of this most dramatic of Renaissance figures as his fame was building, but computational analysis has helped to solve the conundrum of his youthful appearance and unexplained rise to prominence with almost no artistic output.

Index Terms *Face processing Portraiture Renaissance Computational modeling Visual processing 3D reconstruction*

1. INTRODUCTION

Through the millennia, one of the primary goals of the art of painting has been an optical depiction of the scenes of the three-dimensional world that form our visual experience. A key role of paintings has been to depict faces in portraiture, conveying the identity of figures of contemporary and historical interest. The effective recognition of such figures requires accurate interpretation of the 3D configuration of the facial features, which is presently a largely subjective art, given the variety of poses employed. This paper describes quantitative techniques for the analysis of facial expression and 3D facial configuration from the 2D artworks, with specific application to the works of Leonardo da Vinci. There are no accepted portraits of this most dramatic of Renaissance figures as his fame was building, but computational analysis can help to solve the conundrum of his youthful appearance and unexplained rise to prominence with almost no artistic output.

Scholarly opinion varies as to the number of portraits of da Vinci that exist. The red chalk portrait of an old man in the Milan collection of Leonardo's papers (Fig. 1, upper left) is

Figure 1. The most securely established contemporary portraits of Leonardo: Self-portrait, Plato/Leonardo, by Raphael (1510), Leonardo, by Guillaume de Pierre di Marcillat (1520), and Leonardo, by Francesco Melzi (ca. 1510).

the only one acknowledged by Kenneth Clark [1], a foremost authority on Renaissance art and Leonardo in particular.

Even though only one authoritative portrait is recognized, there is an increasing set of portraits purporting to be of Leonardo that are gradually gaining acceptance among Renaissance art scholars. Restricting consideration to

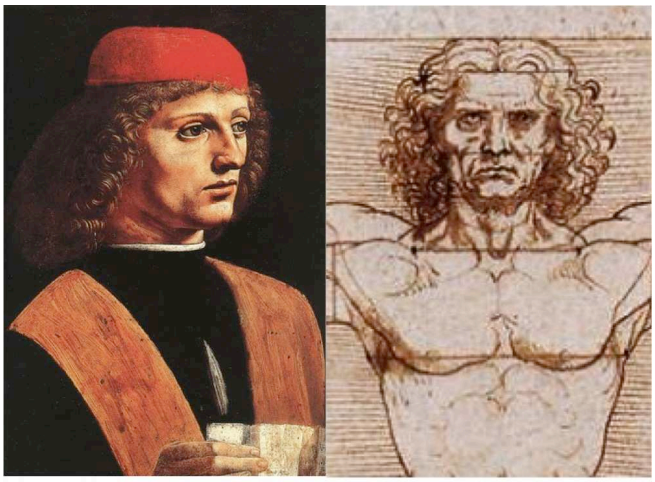
contemporary portraits, just three are known in addition to his self-portrait (Fig. 1): one by Leonardo's loyal pupil, Count Francisco Melzi in the Windsor collection of da Vinci papers, one by Raphael (who knew the artist from his time in Florence in the early 1500s), and a newly discovered work by French stained-glass artist Guillaume de Pierre di Marcillat (who had relocated to Arezzo many years earlier, where in fact he was Giorgio Vasari's master) [2].

However, as a young man Leonardo's appearance is generally regarded as obscure, although he was described by Vasari [3] as of "outstanding physical beauty." This general neglect is somewhat surprising in view of the fact that Vasari states that the statue of David by Verrocchio (Fig. 2), modeled on the youthful Leonardo [3]. This claim is not often taken too seriously by art historians but is given plausibility by the fact that Leonardo was well known to be Verrocchio's favorite pupil, and was just the right age for that role at the time attributed for the sculpture's execution (around 1470, when Leonardo would have been about 20).

Figure 2. 'David' by Verrocchio (~1470), described by Vasari as being based on Leonardo's appearance.

Taking a cue from this statement, there are at least two further portraits which, it is argued, may have da Vinci as their subject. In a video essay, the prolific portraitist Siegfried Woldhek [4] analyzes 120 depictions of faces in Leonardo's work, and uses iconographic criteria to exclude most of them, resulting in just three faces that he considers to be plausible self-portraits by da Vinci: the aged self-portrait drawing of Fig. 1 (upper left), the famous drawing of the Portrait of a Musician (Fig. 3A) and the Vitruvian Man (Fig. 3B), the overlaid images of a man spanning a square and a circle.

The 'Portrait of a Musician', unearthed in the Pinacoteca Ambrosiana, Milan, was originally listed as Portrait of Ludovico il Moro (Ludovico Sforza, Duke of Milan, who was born in the same year as Leonardo), and as painted by Bernardo Luini (one of Leonardo's closest adherents), although the painting has often subsequently been attributed as a (self-) portrait by da Vinci. A cleaning in 1905 revealed that the sitter is holding a piece of sheet music on which can be seen the letters "CANT... ANG..." (most likely meaning "songs of angels"), which would be inconsistent with the identification of the subject as Duke Ludovico, but would fit with the angelic persona attributed to the young da Vinci. Moreover, da Vinci had a great reputation for being able to play any stringed instrument at first sight. Thus, there seems to be circumstantial evidence supporting the identification of the musician portrait as being of da Vinci, regardless of whether it was painted by da Vinci himself or by a contemporary.



A B

Figure 3. 'Portrait of a Musician' (variously attributed) and a detail of the Vitruvian Man, from da Vinci's notebooks, both sporadically suggested as portraits of da Vinci's himself.

The Vitruvian Man is definitively Da Vinci's work, but has only occasionally been suggested as a self-portrait [e.g., 4,5], which is surprising in view of his own pronouncement that "often a master's work resembles himself," and thus that his epitomizing of the human form might well have been taken from his own form. (This attribution is particularly likely in view of the fact that the man's face is somewhat past its prime in terms of the classic Graeco-Roman ideal form). What more natural than for Leonardo the self-described polymath to use his own face as a model for the universal man?

Although none of these three works can be assigned a definite date, they are all generally attributed to the period from 1470-90. The idea that they are all portraits of Leonardo himself would thus, based on the estimated ages of the respective subjects, space them roughly a decade apart from each other, suggesting dates of about 1470, 1480 and 1490, respectively, in rough accord with the consensus art-historical estimates of their dating.

2. METRIC ICONOGRAPHY

Iconography is the study of the significance of the objects depicted in paintings, either on their own or in relation to the overall theme of the painting. It has played a large role in art history since the time of Vasari (1550) [3] and is a largely qualitative evaluation of the explicit and implicit motifs in paintings. Some aspects of iconography, however, are quantitative, such as the analysis of perspective constructions in relation to the compositional structure. This kind of pictorial analysis may be termed 'metric iconography'. The present analysis incorporates a different form of metric iconography, which is the use of quantitative analysis of facial structure in identifying cryptic portraits and self-portraits in works of art. In its simplest form, this analysis consists of the measurement of the proportional distances between pairs of features in frontal views of faces. At a more sophisticated level, it includes the spatial reconstruction of the 3D structure of the face, and quantification of its fit in paintings under question.

The result of such iconographic analysis may give deeper meaning to a painting than is obtainable by a purely qualitative examination. For example, it can reveal that the subject of a painting had a strabismic condition of ocular misalignment, as in the case of Rembrandt's self-portraits [6]. The geometric reconstruction of vanishing points may reveal how the artist intended to use the perspective construction to guide the eye to regions of importance in the painting. A quantitative match in the proportions of different faces may confirm whether they are plausibly a portrait of a particular person (or a self-portrait of the artist). And so on.

In the case of the three images of Figs. 2 & 3, the proportions of 10 features are compared in Fig. 4. Note the broad arched brows and cleft chin in the frontal-pose portraits. The construction lines show the close alignment of the forehead line, eyebrows, nostrils, nose tip, mouth, chin, throat and neck crease. The precision of these alignments is the more remarkable in that these are 15th century drawings, not photographs (of course!), so that their accuracy depends on the visual acumen of the artist in question. Notice also the pale-colored irises of the eyes in the three portraits, the downward curve in the mouth with its prominent lower lip, the cleft chin in the two cases where it is visible and the slight bulge in the middle of the nose in all four images but stronger with advancing age. Although the net configuration of the nose could be seen as straight, he was apparently acutely aware of the details of its configuration.

A B C D

Figure 4. A. Leonardo da Vinci's acknowledged self-portrait in middle age. B. The face of the Leonardesque musician. C. The face of the Vitruvian Man. D. A face from da Vinci's sketchbooks used to illustrate the geometric analysis of facial proportions. Lines indicate the vertical proportions of 10 features in common among most of the portraits, from the crease in the forehead to the jugular notch at the base of the neck.

3. ESTIMATING FACIAL SIMILARITY

A previous study [7] employed a morphable model of three-dimensional face shape [8] to recover the 3D face shape from the 2D image by iteratively solving the morphable model to match the pose and shape of each structure. For reconstruction of faces from the sparse data available in the Renaissance portraits, they used a standard set of feature points (Fig. 5) augmented by additional feature points along the occluding boundaries. The 3D distributions are learned empirically from data assuming a weak perspective model using a generalized expectation-maximization (GEM) algorithm [9]. For the optimization, the 2D variances comprised of two components: a) projected three-dimensional variance due to generalization error of the morphable model and b) two-dimensional pixel error.

Based on the estimate of the camera projection parameters, the error term was globally minimized with respect to the shape parameters by solving a system of linear equations. Conversely, the shape estimate was used to solve the camera projection parameters through a constrained optimization problem from the 2D-3D point correspondences. The algorithm iteratively solved for these two parameter sets until convergence was achieved, within ~10 iterations.

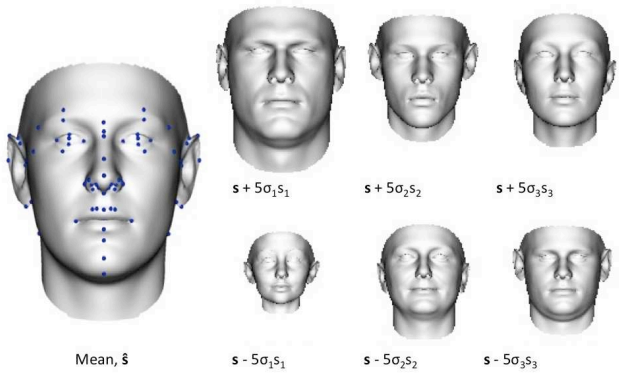


Figure 5. Lefthand image of the 3D morphable human face model, with standard feature points indicated. The other six images show the mean face deformed by ±5 standard deviations along the first three principal modes of variation.

The results for the three putative da Vinci portraits are shown in Fig. 6 (using two different views of the sculpture). The outcome is a 3D model of the face of da Vinci compatible with all four images (excluding the hair region). Three views of this 3D model are shown, with the respective textures overlaid on the model [7]. (A fourth image was included in that study but is not included here for clarity of exposition.)

Figure 6. Three views of the 3D model of Leonardo's face derived from the GEM optimization procedure are shown, with the respective textures overlaid on the model.

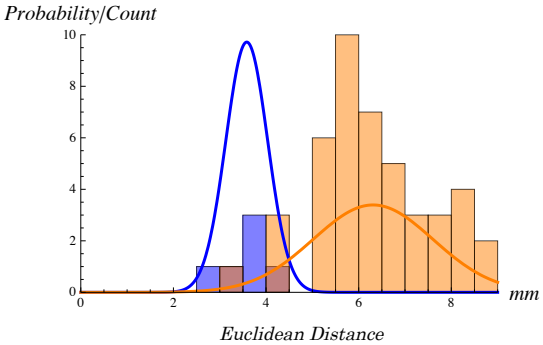


Figure 7. Mauve bars: Mean 3D-3D Euclidian errors (mm) for face shape estimates of Verrocchio's 'David,' Leonardo's 'Portrait of a Musician', and da Vinci's Vitruvian Man. Beige bars: Mean 3D Euclidean errors (mm) between ten control faces and face shape estimates of the three portraits in Figs. 2, 3. Brown bars: overlap between the test and control types.

The relative mismatch errors of the three fits after convergence, averaged over the feature points, are plotted in Fig. 7. Each solution was similar to the others with an average mismatch of about 3.5 mm. These may be compared with the mismatches between the three solutions and a set of other faces from an available database, only one of which is less than 4 mm and which range up to nearly 9 mm. Thus, the 3D models of the three putative da Vinci portraits are far more similar to each other than they are to those of a typical selection of other faces (Fig. 7). The t statistic for this comparison takes a value of 12.1, implying significantly better fit for the putative da Vinci portraits to each other than to the control faces at $p < 0.01$.

3. CONCLUSION

The 3D facing matching algorithm indicates that the face shape from the sculpture and the young and mature portraits are significantly more similar to each other than they are to the sample of control heads. This similarity validates quantitatively the various art historical claims that they represent the progression of da Vinci's appearance at the ages implied by the natural aging of the depicted features, corresponding roughly to ages 20, 30 and 40.

With this extra assurance, we are in a position to develop further attributions as to Leonardo da Vinci's youthful appearance. An array of 12 plausible self-portraits an addition to the two used in the computational analysis is aggregated in Fig. 8. These were drawn or painted with a range of different purposes, from preliminary sketches to finished allegorical figures, some by himself alone and some

in collaboration with other artists both senior and junior to him, ranging from early to late in his life, and from young to middle-aged. From left to right by row, they are a) the 'St Sebastian' (Cleveland Art Museum) attributed to Ambrogio de Predis (da Vinci's collaborator on the 'Virgin of the Rocks'), but sometimes considered to show the influence of the master's hand; b) Verrocchio's sculpture of St Thomas, on which da Vinci would have played a key role, and suggested in [7] to be modeled on him at about age 25; c) da Vinci's sketch of the head of Jesus for the 'Last Supper' (Musee de Beaux Arts, Strasbourg); d) the Milan 'Portrait of a Musician'; e) a Verrocchio bas-relief of 'Alexander the Great' (National Gallery of Art, Washington, DC), on which da Vinci was a likely collaborator; f) the young philosopher from da Vinci's 'Adoration of the Magi', often suggested to be a self-portrait; g) the young foot soldier from Rubens copy of da Vinci's unfinished 'Battle of Anghiari', suggested here to be a da Vinci self-portrait as the observer (or endangered recipient) under the hooves of the violent action of the horses; h) da Vinci's late painting of 'Young John the Baptist' (the Louvre); i) 'Young Bacchus' (the Louvre), often attributed to da Vinci ; j) the face of one of the many crowd figures in da Vinci's study for 'Adoration of the Magi'; k) 'Salvator Mundi', often considered to be a copy of an original by da Vinci, sometimes suggested to be a self-portrait; l) a study for 'John the Baptist' sometimes attributed to da Vinci; m) the head of da Vinci's 'Vitruvian Man', which has been likened to a self-examination in a mirror; n) a study facial proportions from da Vinci's notebooks, which again has the appearance of the artist scrutinizing his physiognomy in a mirror.

Thus, these heads are all associated with the hand of da Vinci in one way or another, although the attributions as self-portraits are admittedly speculative in many instances. Given the range of ages, styles and collaborators, they should therefore not be expected to convey the appearance of a photographic match to each other. However, the almost all have shoulder-length hair in the tight curls historically associated with his youthful look, and a general physiognomic similarity with broad regular brows. Many have an enigmatic expression reminiscent of the renowned 'Mona Lisa smile', strongest in the younger visages and fading with advancing age as the mouth turns progressively down, from his years in the Verrocchio studio to the challenges of existence in the Sforza court.

The individual claims of each image to be a da Vinci self-portrait are further strengthened by the physiognomic similarities of the features across the set. We thus obtain a fleshed out view of the intense young man who became the quintessential Renaissance figure.

Figure 8. A montage of 14 probable da Vinci portraits of himself in his younger to middle-aged years.

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