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Using 3D scanning to analyze a proposal for the attribution of a bronze horse to Leonardo da Vinci

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Abstract

In this paper we present how technologies developed in the context of 3D graphics (3D scanning and image-to-3D-model mapping) have been used to evaluate in a metrically objective way the plausibility of an attribution hypothesis of a Renaissance artifact. The artifact considered is a small bronze horse (Archeological Museum, Florence, Italy), which was discovered to be very similar to a silverpoint drawing by Leonardo (Leonardo drawing #358, Windsor Royal Library, UK), thus originating an attribution hypothesis.
A highly accurate digital replica of this small bronze statue was reconstructed by means of triangulation-based 3D scanning technology. Using image-to-3D-model mapping techniques the Leonardo's drawing depicting a very similar horse has been aligned to the digital 3D model, reconstructing in a virtual manner the ideal vantage points which could have been used to sketch the drawings of the horse (in the hypothesis that Leonardo had drawn it by directly looking at the bronze). The same approach has been also tried with other Leonardo's drawings depicting a similar subject, but none of those was sufficiently compatible in shape with the bronze horse to allow convergence of the image-to-3D mapping process.
The approach proposed allows us to give some visually objective evidences about the shape similarity issue, which was the origin of this attribution attempt. At the same time, a purely technical evaluation does not close the attribution issue. Further archival research and expertise will be needed to solve and assess the issue of this disputed hypothesis.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Digitizing and scanning, I.3.8 [Applications]: Cultural Heritage

1. Introduction

In the recent years, technology has become more and more important as a mean to support the study, restoration and dissemination of our Cultural Heritage (CH). Innovative techniques for digital 2D/3D acquisition and visualization are now very widely used for the dissemination and easy fruition of different types of CH content. Moreover, scientific analysis of materials has become one of the most important proofs for chronological attribution. Spectroscopy and investigation by X-rays have been widely used to analyze drawings, paintings, pottery (some examples are [Mig04, MPMG06, ABB*01, SDKS04]); moreover, techniques of genetic analysis [CLFC*07] and pigments analysis [Man07] could lead to really interesting, if not revolutionary discoveries.

In this paper, we present a project in which acquisition (3D Scanning) and visualization techniques are used to support the analysis of the attribution proposal of a small bronze horse to Leonardo Da Vinci. Even though not conclusive, the results of the experience provide new evidences for the continuation of the debate on this attribution hypothesis.
The organization of the paper is as follows. The attribution proposal, the results of previous archival research and an analysis of the competing theories are presented in Section 2 and 3. Then, we present in Section 4 the approach adopted to assess the attribution proposal by using 3D graphics technologies: the reconstruction of the 3D digital model of the bronze horse, how do we matched the bronze with the Leonardo's drawing and finally the results of some attempts

Figure 1: *The Windsor silverpoint drawing (WRL #12358: The Royal Collection ©2007 Her Majesty Queen Elizabeth II).*

Figure 2: *The small bronze horse (Archeological Museum, Florence).*

to match the bronze horse with other artifacts. Conclusions are presented in Section 5.

2. The attribution hypothesis

Fondersmith's attribution hypothesis is that the Leonardo metalpoint (RLW #12358, see Figure 1) is an optically-traced drawing of a small bronze horse (inv. #19446, Archeological Museum, Florence, see Figure 2). According to this hypothesis, the small bronze horse was modeled and cast by Leonardo, while an apprentice of Verrocchio (1470-1480.) Later, Leonardo used the small bronze horse as a reference for the Windsor metalpoint (1480.)

Leonardo could have used a camera obscura (or some other optical device) to create the Windsor metalpoint. He

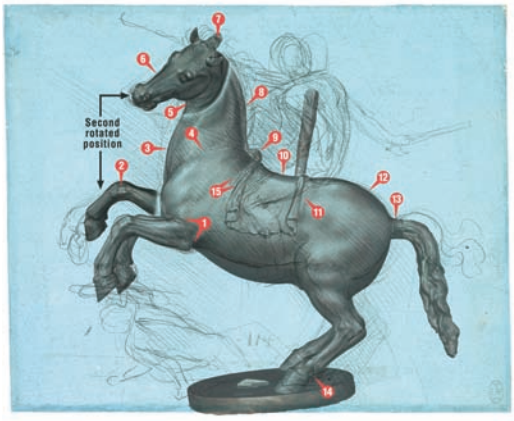

Figure 3: *Scheme of the possible points in common between the statue and the drawing (graphic by C. Broz and M. Fondersmith).*

traced the small bronze horse in 2 stages: first, the body, and then he rotated the head after rotating the bronze to the left. The two sets of front hooves are evidence of the rotation. The re-drawn neckline shows how Leonardo reconciled the second angle of the head with the original profile. The precisely crosshatched areas of the drawing describe the sculptural form of the small bronze horse. There are many points in common between the drawing and the sculpture. They seem too numerous to be coincidental, some of them are (see also Figure 3):

1. The left forearm from the wrinkle to the elbow
2. The right forearm (from the 2nd rotated position)
3. The front profile of the neck
4. The double line between the neck and shoulder
5. The wrinkles on the neck
6. The head, eyes, mouth, and ear (from the 2nd rotated position)
7. The tufted forelock
8. The clipped mane
9. The tuft at the withers
10. The seat of the saddle
11. The general outline of the saddle
12. The rump or croup of the horse
13. The wrapped tailhead
14. The rear hoof
15. The saddle fold

The saddle fold is a unique feature of the small bronze horse and appears in the Windsor metalpoint. This may be solid proof that the Windsor metalpoint is optically traced from the small bronze horse. The shifted position of the traced fold suggests that it may have been drawn after Leonardo rotated the bronze to draw the head. It is as if

Figure 4: *The horse and rider group (Archeological Museum, Florence).*

Leonardo started to draw the saddle folds, realized the shifting had occurred and stopped after tracing one fold.

The differences between the sculpture and the drawing can be explained by the fact that the bronze was merely a reference. So Leonardo felt free to make changes and improvements: the body of the horse is thinner and the tail and mane are more dynamic. The metalpoint is perhaps the first design for the equestrian monument to Francesco Sforza, a never completed project that was to occupy off and on nearly twenty years of his life. The carefully rendered parts of the drawing, with his distinctive diagonal cross-hatching, were traced from the small bronze horse. But the metalpoint is an exercise in problem solving. One problem was how to support the enormous weight of a rearing horse given the weak tensile strength of bronze. The solution was to buttress the front hooves with a fallen warrior. Another problem was how to position the rider. Leonardo tried 2 positions for each arm. The left arm is first shown near the horse's neck. Then emphatically redrawn at the rider's hip, forming a strong diagonal that reins in the horse's head. The right hand holding the baton is drawn in front and in back of the rider.

Which came first: the sculpture or the drawing? It is more probable that the horse was modeled first and the drawing was traced from it. It is technically easy to trace a static sculpture with an optical tracing device like a camera obscura. A 3D object can be easily projected on a 2D surface. It is technically very difficult to do the reverse - to base a sculpture accurately on a drawing. Artists often create 3D models as a basis for paintings or drawings but sculptors are more likely to create small modellos rather than drawings, as the basis for larger sculptures.

The Windsor metalpoint has been dated around 1480, shortly before Leonardo left Florence for Milan. The bronze could have been created at any point during Leonardo's apprenticeship with Verrocchio. It is probably one of many small horses he modeled to study equine anatomy and to use as reference for projects like the "Adoration of the Magi" (Uffizi). It was modeled in wax and cast by the lost-wax process. The bronze casting may have coincided with one of Verrocchio's numerous bronze commissions.

A request has been made of the Archeological Museum to allow a metallurgical and casting analysis of the small bronze horse in order to compare it with the Verrocchio bronzes. This Leonardo sculpture hypothesis was formed in 1973 during undergraduate study at Syracuse University in Florence, Italy. It was the subject of an unpublished academic paper in 1975. It was resubmitted to scholars in 1984 and 1998 when it was published in [Fon98]. Finally, in 2006, the scanning of the bronze provided additional material for the discussion about this attribution proposal.

3. Results of Archival research and competing attribution theories

How the small bronze horse came into the collection of the Archeological Museum is not fully understood. In 1973 museum curators said it came from the "old Medici collection".

In early 1984, Fondersmith shared his Leonardo attribution proposal with the eminent art historian John Pope-Hennessy, and solicited his professional judgment. Pope-Hennessy proclaimed that the small bronze horse was from the "school of Riccio" (Fondersmith relayed this attribution to Dr. Carlo Pedretti, see below). But in 1985 [PH85], John Pope-Hennessy attributed the small bronze horse to Benvenuto Cellini, citing documentary evidence that Duke Cosimo I de'Medici commissioned a small bronze horse from Cellini specifically to display a small Etruscan rider in the Duke's collection [Plo83] (see Figure 3.) This attribution has been accepted by the Archeological Museum to this day. The similarities with the Windsor metalpoint were not considered. Moreover, another difficulty with the Cellini attribution theory is that the horse and rider fit together so awkwardly. The rider is too large for the horse. A foundry rod was screwed into the saddle of the horse to hold the rider in place. Cellini, a supreme craftsman, would surely have created a horse to fit the rider perfectly.

In a letter dated May 7, 1984, Dr. Carlo Pedretti, then Professor of Art History at UCLA, wrote: "The bronzette on which you have been working is included among the antiques discussed by F. Malaguzzi Valeri [MV22]. I am inclined to agree that it is a Renaissance piece, possibly from the Riccio circle, in any case reflecting Leonardo's ideas and

Figure 5: *A screenshot of the colored 3D model obtained with 3D scanning.*

certainly superior to anything I have ever seen of the kind. It is a piece that deserves the full attention you shown to be able to give it and I hope you will publish a note on it." The bronze horse statue can be found in the appendix of all Leonardo-like sculptures found by Valeri in Florence, but no reference to the metalpoint is present.

4. Some years later: using 3D graphics to assess potential similarities

Visual Computing Lab has been contacted for executing an accurate digital acquisition of the bronze, with the purpose of performing further study on a physical replica produced from the digital 3D model via rapid reproduction technology. After having acquired the digital model with 3D scanning technology, we proposed to do some shape similarity tests using a proprietary image-to-3D-model aligning tool. The results of these activities are presented in the following subsections.

4.1. 3D scanning of the bronze horse

The 3D scanning of the bronze statue was performed with a Konica Minolta VI 910 Laser Scanner; 170 range maps were acquired from the small bronze (spanning 28 cm from the ears to the tip of the tail) at the highest sampling resolution supported by the scanner. A highly detailed 3D model (3.5 million faces) was produced from those sampled data.

A comprehensive photographic campaign was also performed, and the photo set was used to project color information on the 3D model, in order to produce a very realistic digital copy (see Fig. 5).

Figure 6: *Images from the first alignment (main body).*

4.2. Finding a camera for the bronze-drawing matching

To perform a shape comparison between the digital 3D model of the bronze horse and the Leonardo's 2D drawing we can use some technology developed to map color data, sampled with standard images, to the surface of a 3D model.

In order to be able to project color information on a 3D

surface it is usually necessary to register each photo to the 3D model; in practice we need to find the position in the space of the camera and the value of some internal parameters (focal length, lens distortion).

The issue of registering uncalibrated images to a 3D model has been discussed in several papers [LWG97, KNZI02, JC04]. Completely automatic registration can be achieved only under particular assumptions (e.g. [LHS00]), otherwise user intervention is necessary. Algorithms which estimate parameters need some correspondences between the image and the 3D model, i.e. the selection of some corresponding point pairs. After this approximate selection, an error minimization method is applied to find the best possible alignment. We developed a tool, whose main features are described in [FDG*05], to register a big number of photos on a 3D model in a fast and user-friendly way.

In order to try to produce shape similarity evidences to help assess the attribution proposal, it was decided to treat Leonardo's drawing as if it was a photo. Will the camera positions and the alignments found be compatible with the use of a camera obscura? Will the matching details listed in Section 2 be effectively coincident?

The alignment of the drawing was performed in the usual way: some correspondences points between the 3D model and the drawing were indicated. The correspondences on the drawing were set by following the indications provided by the attribution hypothesis. We concentrated on the two proposed points of view (see Section 2): the first for the body silhouette and the other, rotated, for the head. Clearly the points provided for the registration were different for the two cases. The minimization algorithm estimated the camera position which best fitted the correspondences; the focal length was fixed to a plausible value for the use of a camera obscura. The results of the first alignment are shown in Figure 6, where the overlapping of the 3D model and the drawing is shown at different transparency levels. As it can be noted, the alignment of some parts of the drawing is surprisingly precise: the lines of the neck and the back are coincident with the silhouette of the model, and the profiles of both fore and hind right legs are quite similar. Moreover, the position of the associated camera (denoted by a cone in the right-most section of Figure 7) is clearly compatible with the point of view of a person using a camera obscura.

The second alignment was performed to validate the second proposed position, from which the head would have been sketched. Results are shown in Figure 8: not only the profile of the head is very similar to the drawing, but also the line of the neck is overlapped to an internal line in the drawing. Moreover, the line indicated in Section 2 is effectively coincident with the position of the saddle fold in the model. The associated camera position (Figure 9) shows that the point of view is not only rotated but also raised with respect to the first alignment.

The results of the alignment provide a visually significant proof and confirm the compatibility of the use of a camera obscura to sketch the drawing from the bronze statue. We would like to stress that no deformation has been introduced while performing the image-to-3D mapping. Two images of zoomed-in details are presented in Figure 10.

Figure 7: *Relative position of the camera for the first alignment*

Unfortunately, in this case it's very hard to provide numerical proofs of the quality of the alignment: this can be done with photos, which reproduce exactly the object, but it would be of no utility in this case, where the drawing is clearly not a mere tracing of the silhouette. Anyway, the surprising alignment obtained seems to be too precise to be casual, especially considering the results obtained on similar objects (see next Sections).

4.3. Checking possible matching with other Leonardo drawings

The immediate objection to the results shown in the previous Section could be that, even though the alignment is very good, similar results could be achieved with other drawings. In this section we show the results obtained by trying to align other Leonardo drawings to the 3D model. The purpose of this attempt was to find if the bronze horse could have been associated to other works of Leonardo. Several other examples of horse drawings are currently kept in museums all around the world. Some of them have been considered here for further investigation (see Figure 11).

The alignment results show that in no case it was possible to achieve overlapping as good as the ones found for drawing #19446. In some cases, as for the example shown in Figure 12, a partial alignment can be found, by flipping the image, but the position of the fore and hind legs is not coherent with the rest of the body.

4.4. Checking for shape similarity with other bronze horses

Another point raised by the curators of the Archeological Museum is that the typology of the bronze horse is very common, even more when we consider Roman art. According to their knowledge, many similar items are exposed in

Figure 8: *Images from the second alignment (head).*

museums around the world. The Archeological Museum in Florence holds another bronze horse (see Figure 13) which is very similar to the one we are studying and comes as well from the old Medici collection (it is also mentioned in [Cal88] as a very similar artifact which could have been font of inspiration for the one we are studying).

To check this potential similarity between this second

Figure 9: *Relative position of the camera for the second alignment.*

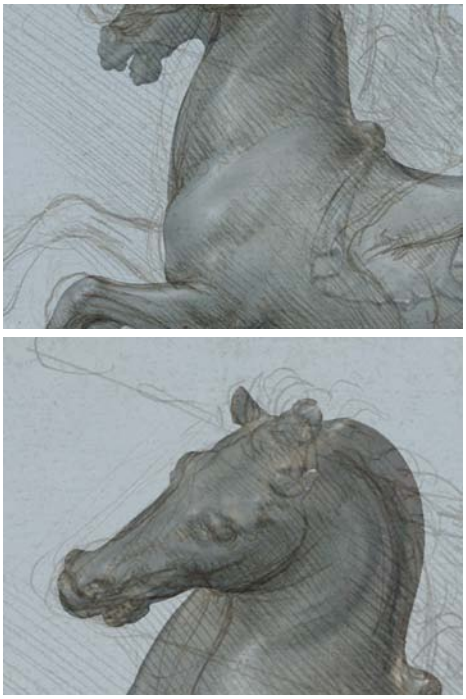

Figure 10: *Two detailed view on the neck and saddle region (top) and on the head (bottom).*

horse and the Leonardo drawing, we adopted the same procedure: let us check if this second horse has some major shape similarity with the one we are considering. This can be implemented by checking if images taken from the new horse can be aligned to the 3D model of the latter. The results of this registration attempt (see Figure 14) show that no plausible overlapping is possible, and that the shape of the two bronze statues is so different that it is very unlikely that one could have been inspiration for the other; even though the position of the horse is similar, this registration attempt

Figure 11: *Some of the other drawings on which image-to-3D alignment was also tried (top, ©The Royal Collection 2007, bottom ©The British Museum).*

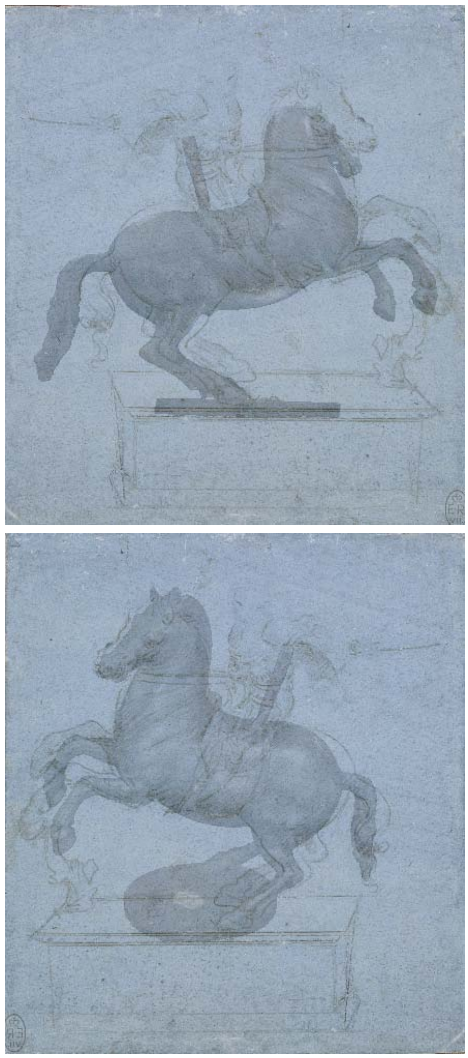

Figure 12: *Results of alignment for another silverpoint drawing by Leonardo*

demonstrates that horse shapes can be very different one from the other. On the base of these evidences, we deduct that the attribution hypothesis can be applied only to the originally spotted statuette.

5. Conclusions

The paper presents the results of a research where modern 3D graphics technologies have been used to give evidence to a shape similarity problem linking a 3D artifact, a bronze statuette historically attributed to Cellini, and a 2D representation, a Leonardo's drawing. The joint use of accurate scanning and accurate image-to-3D-model reprojection technologies made it possible to give evidence to the asserted impressing shape similarity of these two artworks. At the same time, we also demonstrated that the same similarity does not hold in the case of similar Leonardo's drawings, or among similar bronze statuettes.

Obviously, this does not say the last word to the long lasting dispute relative to the attribution of the bronze horse, but it helps rising some serious concerns on the current attribution (i.e. to Cellini). The debate should be solved by further study or analysis of the constituent material.

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Figure 13: *The second horse (hellenistic period, Archeological Museum, Florence).*

Figure 14: *Registration of 3D model on the bronze horse image (main body).*

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