Do Weave Matches Imply Canvas Roll Matches?

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Abstract

Computational algorithms for measuring thread counts from scanned x-rays produce warp and weft thread count “maps” across entire paintings. Within the database of over 300 van Gogh paintings, we found a clique of 44 warp-weave-matched paintings. By reconstructing the smallest canvas section that could have produced this match, they must span the entire width of a commercial canvas roll (2+ meters) and more than 13 meters of length, much longer than a single roll (10 meters). Several grounds were found, further suggesting these matched paintings came from separate rolls. Investigation showed that commercial priming firms cut rolls from longer bolts.

Introduction

The recent introduction of computer-assisted and computer-automated thread count algorithms has not only greatly eased the tedium of measuring the vertical- and horizontal-thread densities from x-rays, but also provided more information about how thread densities vary across a painting (Johnson et al. 2009). The algorithms not only measure thread densities across an x-ray, but also thread angles: the departures of the horizontal and vertical threads from coordinate axes. These angle measurements provide immediate information about the presence and degree of cusping.

Thread densities are depicted as *weave maps* that use colors to illustrate how the thread densities vary across a painting (Fig. 1). These maps reveal that thread density variations can typify the painting’s canvas support. For example, a canvas’s vertical thread counts persist across the height of the painting, but vary horizontally in a seemingly random fashion. The horizontal threads show a similar variation, but with persistent horizontal counts that vary vertically. In other words, thread packing varies across the painting’s support. These variations in canvas thread densities are not specific to each painting, but characterize the larger canvas from which the painting’s support was cut. Consequently, thread density variations serve as a fingerprint for the canvas, allowing painting weave maps to be compared in a search for matching weave patterns. We have also found that thread angle maps (Fig. 1) help in determining painting position and, surprisingly, reveal aspects of the canvas weaving process. These interpretations result from understanding the commercial priming process: how canvas is delivered, how canvas rolls are cut from a longer length of canvas—known as a *bolt* of canvas—and then mounted on a priming frame, and how the primed canvas is stored and delivered to retail outlets.

This paper describes how weave matches are determined and illustrates how matching canvas support information can be used in art history. Angle maps coupled with knowledge of commercial priming operations supplement the weave matches, confirming painting support placement (for example, does cusping along a painting’s edge confirm placing the support along an edge of a commercially primed strip of canvas).

We focus on the paintings of Vincent van Gogh for several reasons. First of all, a large fraction of his oeuvre is concentrated in a few museums. But more important are the detailed insights into his painting practices provided by the copious and well-preserved correspondence with his brother Theo, a Paris art dealer, and several artist friends (Jansen et al. 2009). Not only do the letters describe (in varying amounts of detail) what paintings were executed when, but also when he asked his brother for a new canvas roll and when shipments were received. Furthermore, the letters reveal that, particularly in his later periods, he was very specific about the kind of canvas he wanted [1]. On the one hand, we discovered that his preferred grade of canvas could be easily counted from x-rays, allowing accurate count estimates. On the other, this specificity could complicate the ability to localize weave-matched paintings to a specific roll. Could matching paintings come not from the same roll, but instead from different rolls cut from the same bolt?

Interpreting Weave and Angle Maps

Thread count (density) measurements are made with the algorithm described elsewhere (Johnson et al. 2009). The weave maps shown in Fig. 1 represent the thread count measured every 0.5 cm for the surrounding 1 cm square as a color, which allows a ready visual representation of thread count variations across a painting. The horizontal- and vertical-thread weave maps look very different. Here, the horizontal-thread densities (counts) vary less (have a more consistent color), have a more persistent count along the thread direction, and vary more rapidly vertically than the corresponding features in the vertical-thread weave map. From this and many other examples, these features typify how weave maps allow quick determination of warp/weft direction: the horizontal threads in F671 correspond to the warp direction [2]. Because warp and weft threads are handled differently in the weaving process, they have different thread count characteristics. Van de Wetering (1997) noted that, for hand-woven seventeenth century canvasses, warp threads tend to vary less than weft threads. We have found this criterion to be reliable in 80-90% of van Gogh's paintings we have examined. By exploiting the features just described, we believe that weave maps can provide additional criteria that will improve warp/weft judgment.

Angle maps provide different information. If the canvas weave were perfect, with the horizontal and vertical threads crossing each other at right angles, the measured thread angles should be zero, which corresponds to a light golden color. The horizontal-thread angle map shows such consistency except near the bottom of the painting, where the color variation suggests the horizontal threads are waving up and down slightly. Such variations indicate cusping, in this case strong cusping. Because cusping occurs only along one side of the painting (none along the top and the vertical-thread angle map shows no cusping), the canvas support must have been primed (sizing or ground applied) not on the painting's strainer, but on a larger priming frame. If there had been cusping on four sides, then the interpretation would be that the primer was laid on unprimed canvas after it had been tacked to the strainer.

Weave Matching Procedure

The first step in the weave matching procedure is to determine whether the thread-count histograms agree sufficiently. We find the best agreement between the two pairs of measured thread counts (does the horizontal and vertical thread count from one painting agree most with horizontal and vertical from another painting or with vertical and horizontal?) and use a detection-theoretic technique to determine the degree of agreement (Johnson et al. 2010). Only if the histograms agree sufficiently—what we call a *count match*—do we consider determining if the two x-rays have a weave match [3].

Once a count match has been found, we calculate deviation maps for a painting's x-rays and determine warp/weft directions. We then collapse the deviation maps along their count-persistent directions (horizontal direction for horizontal threads, vertical for vertical threads) to obtain what we term a *profile* that summarizes thread count variations. We then correlate the pairs of profiles to determine if they sufficiently agree to declare a match. In more detail, we take the vertical and horizontal profiles from two x-rays. We first correlate vertical-with-vertical, horizontal-with-horizontal, and retain the pairing that yields the largest correlation (Johnson et al. 2010). Just relying on this comparison does not take into account the various possibilities for how a canvas section cut from a larger sheet could have been oriented: it could be rotated arbitrarily and, if not pre-primed, flipped over. Letting v_i denote the vertical profile for painting i, h_i its horizontal profile, and rev(•) the operation of reversing a profile, the largest of the following eight pairs is selected to represent a possible weave match: $v_1 \longleftrightarrow v_2$, $h_1 \longleftrightarrow h_2$, $v_1 \longleftrightarrow h_2$, $h_1 \longleftrightarrow v_2$, $v_1 \longleftrightarrow \mathrm{rev}(v_2)$, $h_1 \longleftrightarrow \mathrm{rev}(h_2)$, $v_1 \longleftrightarrow \mathrm{rev}(h_2)$, $h_1 \longleftrightarrow \mathrm{rev}(v_2)$. The degree of correlation of the maximal pair must exceed a threshold to declare a calculated weave match. Because warp and weft threads have different characteristics, the threshold for weft matches is lower than for warp matches.

Once the x-rays for two paintings are calculated to have a weave match, we have found we must observe the match by constructing deviation maps for the entire paintings and comparing them in the suggested alignment. Warp thread matches suggested by single-x-ray calculations usually survive full-painting evaluation, but not weft matches. The wide-stripe characteristic of weft threads can produce a calculated match just because two wide stripes happen to match. Such potential matches may not persist across a larger segment of canvas, which can easily span more than one x-ray. In such cases, the matches are discarded. Figure 2 shows a typical warp-thread match. In several cases, warp-thread weave matches allowed us to align several paintings that do not all match each other. As Fig. 2 shows, F659 and F617 do not have a warp-thread weave match. But, because F386 matches each, we indirectly have a weave match between the first two. In this case, the third painting straddles the other two and brings the paintings together. We term the paintings that share a weave match in this way a *match clique*.

Interpreting Weave Matches

A reason to determine weave matches is to locate the relative positions of two paintings on a canvas sheet. Once a warp- or weft-thread weave match is found, the two paintings are aligned in one direction but the distance between them in the opposite direction cannot be determined. For example, if the warp-thread deviation patterns match (as in Fig. 2), their lateral alignment is known, but they could be close together or far apart in the warp direction. The opposite holds true for weft matches, but these are far more constraining because canvases are narrower in the weft direction.

The location of warp-thread matches in the weft direction on the canvas sheet can be further detailed by considering the angle maps. Angle maps reveal the presence of cusping in a painting. Strong, so-called primary cusping occurs when the canvas sheet is stretched, sized and primed; the sizing and primer (ground) seal the thread deviations that occur at the fixture points on the priming frame. If primary cusping occurs on all four sides of a painting, the canvas was first cut to size and stretched on the working-size frame before it was prepared for the artist's use. In this case, preparatory size and ground layers only cover to the front edges of the picture area, but do not extend onto the tacking margins that were folded over the sides of the stretching frame. If primary cusping occurs on one side, two opposite sides, or not at all, the painting's support was primed on a larger priming frame and the support cut from the larger primed canvas. In this case the preparatory size and ground layers coat the tacking margins of the picture support too. If a painting's angle map reveals primary cusping on one or two opposite sides, that painting's support was cut from the edge(s) of the sheet and a painting that weave matches in that direction should also show cusping. The absence of primary cusping implies the support did not originate from the sides of the sheet.

Van Gogh repeatedly requested ten, occasionally five, meters of canvas, corresponding to a whole or a half-length length (warp direction) of a commercially primed roll that usually measured about 2.10 m wide (weft) [4]. The largest weave match clique we have found among van Gogh paintings in our database contains 44 paintings, while spreading across a little over 2 meters in weft, must encompass more than 13 meters of canvas in the warp direction, much larger than what van Gogh ordered. Fig. 2 shows five aligned paintings from this clique. Furthermore, ground analysis of a subset of paintings in this clique reveals at least two different ground compositions, which coincides to the paintings' chronology (paintings having the same ground have similar dates). Clearly, weave matches don't necessarily imply roll matches. Exploring the practices of commercial priming firms reveals that canvas rolls were cut from a much longer sheet we term a *bolt* [5]. Common practice in manufacturing artist-grade canvas was to produce 100 m or 200 m long bolts, which were shipped to a commercial priming company as an accordion-style stack, probably because a stack can be more efficiently shipped than a large roll. The company would cut each bolt into rolls, making each a little more than 10m long, and prime each separately.

What follows is a description of one company's sizing and priming procedure that fits with our findings on van Gogh's works, though variations on this method are known to have existed during his period [6]. A priming frame is depicted in Fig. 3. The short ends of the cloth were folded and nailed to upright bars. One bar was affixed to the end of the priming frame and then the other bar attached to the other end of the frame, stretching the canvas taut in the process. The top of the canvas was then pushed onto a set of spikes protruding from the frame. A set of hooks inserted through the canvas's bottom edge and then laced with a length of rope to the frame that stretches the canvas vertically. The nail/hook system stretches the canvas in the weft direction, which has the effect of creating cusping in the warp threads (see Fig. 3). The intervals between the fixed spikes at the top were typically shorter and more consistent than that between the hooks inserted each time by hand along the bottom. Consequently, cusping should differ along these edges [6]. Because the canvas ends are nailed to the *sides* of the end bars and the primer does not extend to the tack locations, one should not expect cusping in the weft direction [7]. After the primer has been applied and has dried, the canvas is removed from the frame and rolled onto a rod for shipping to the client. If the firm had a good customer that repeatedly asked for rolls of the same grade of primed canvas, it would hold them in reserve, shipping them upon request.

Conclusions

The weave pattern introduced by slight manufacturing variations can be used to search for warp- and weft-direction weave matches. In our experience, warp-direction weave matches are very sharp and well defined; weft-direction matches are generally much more vague and ill defined (Hendriks et al. 2010).

For commercially primed canvas from van Gogh's era, when one finds a warp-direction weave match among a set of paintings, the best that can be claimed is a *bolt* match, not necessarily a roll match [8]. Since ten to twenty rolls comprise a bolt, bolt matches by themselves say little about the timing of warp-matched paintings. Other considerations must be brought to bear to assign paintings to the same roll, which would suggest a close temporal relationship.

- Paintings having a weft-thread match must come from the same roll. Unfortunately, it is difficult to find such matches. Longer lengths of canvas must overlap than required for warp-direction weave matches.
- The build-up and composition of the sizing and ground layers for paintings from the same roll must be the same for commercially primed canvas. Priming firms used a variety of grounds, but only one type was used on a roll. Of course, different rolls could have the same ground, but if warp-matched pre-primed paintings have different grounds, they must

have come from different rolls. These differences further point to different rolls within the same match clique.

- van Gogh's correspondences describing paintings he executed at about the same time can help localize paintings to a roll. However, it is not always possible to identify the pictures mentioned with certainty, as in the case of some of his repetitions or serial versions of the same theme. For example, there are five *La Berceuse* paintings, six *Postman Roulin* paintings, and seven *Sunflower* paintings, all painted during his time in Arles [9].

We are working to determine other criteria so that paintings can be located on a canvas roll rather than a bolt, which would provide further insight into the artist's process.

Figures

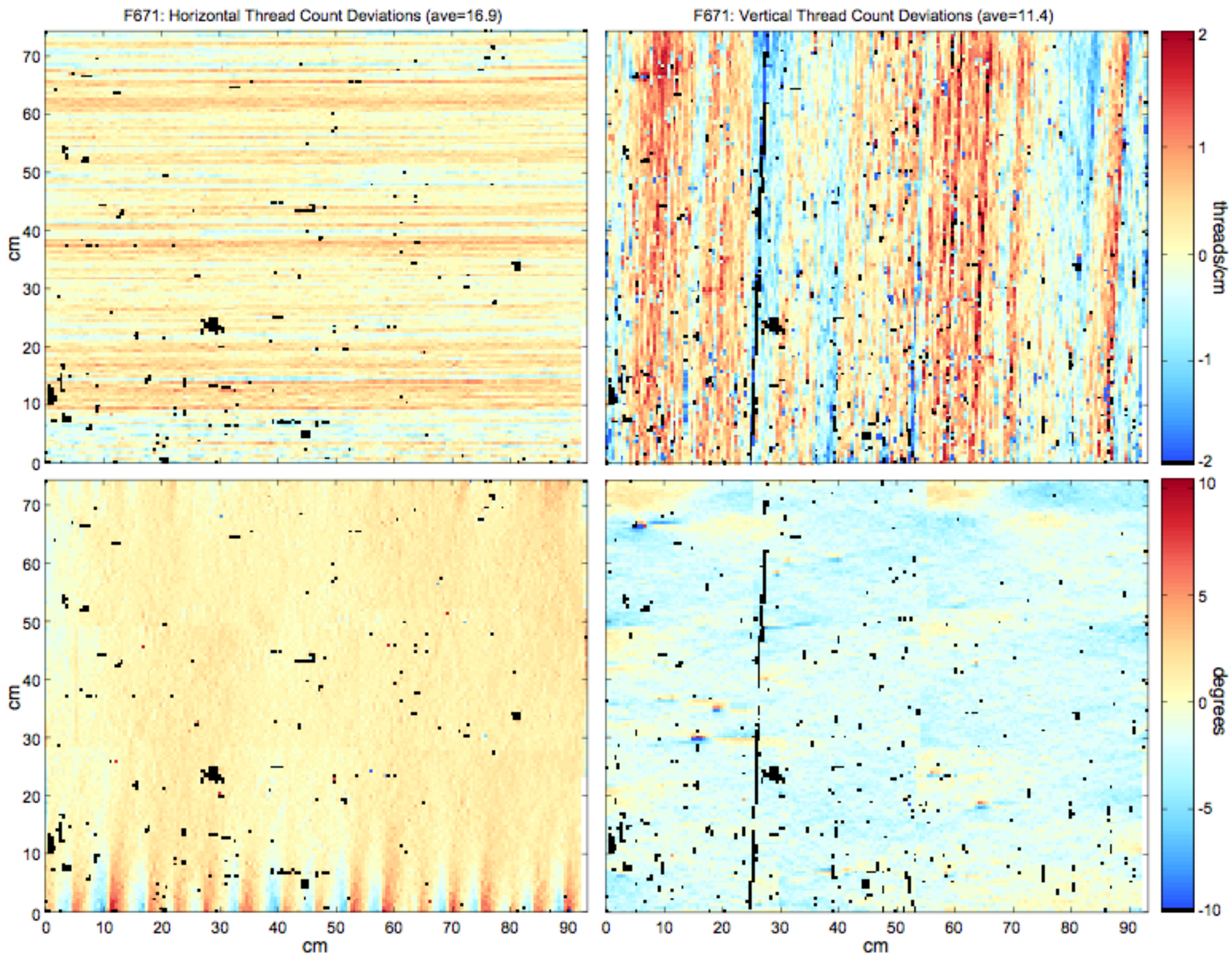

Figure 1. Example of weave maps (top row) and angle maps (bottom row) for the van Gogh painting *Blossoming Almond Tree* catalogued (de la Faille 1970) as F671. The colorbars on the right show how to convert colors into measured thread counts (as differences from painting average) and angles. For F671, the average horizontal thread count is 16.9 threads/cm and the vertical average is 11.4 threads/cm. Black indicates where no measurement was made because the algorithm could not extract a count due to poor legibility of the canvas weave in the x-ray. The warp direction corresponds to the horizontal threads and the horizontal thread angle map shows strong cusping along the bottom of the painting.

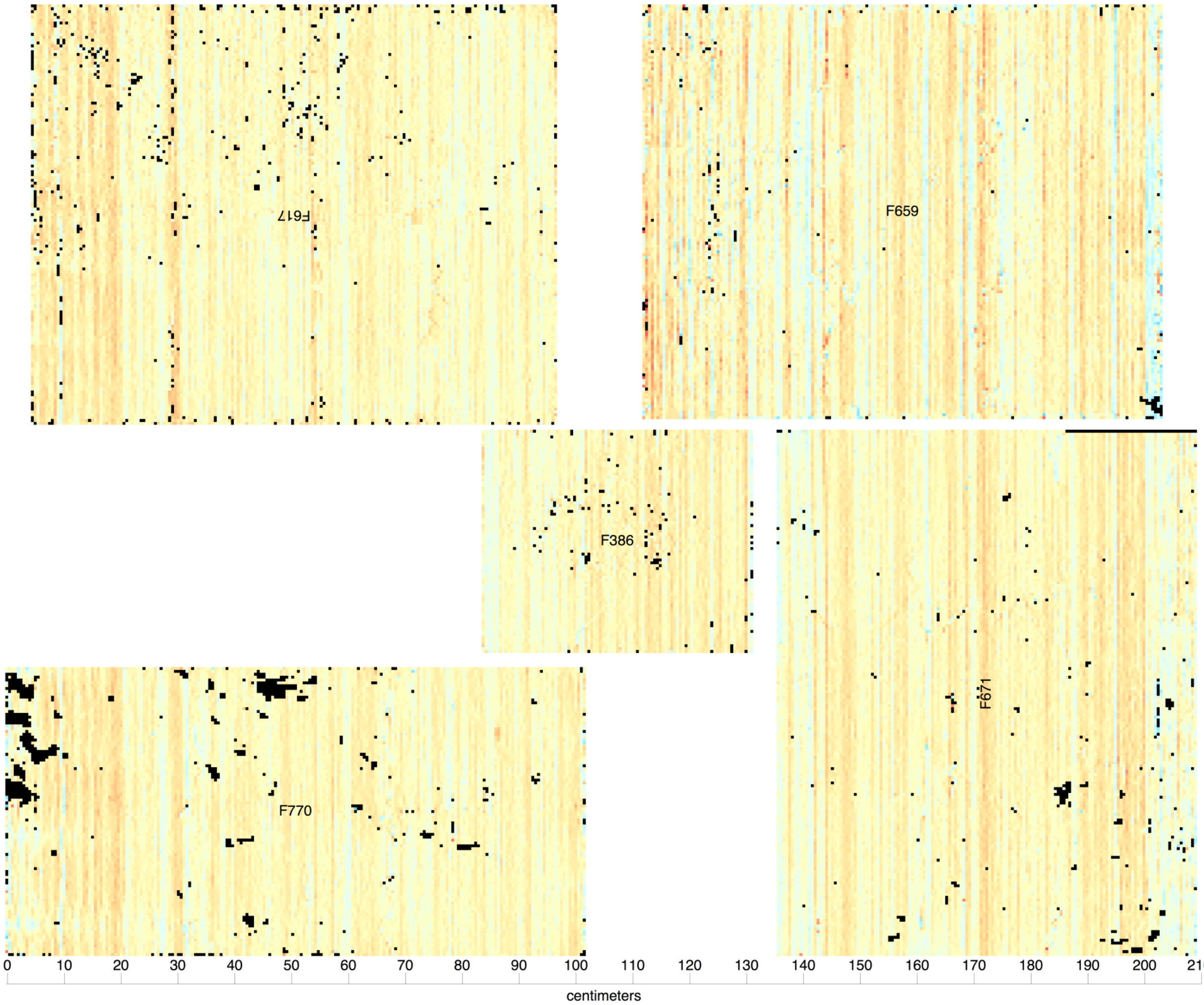

Figure 2. Aligned warp-thread weave maps for five of Vincent van Gogh's paintings F386 (*Still Life with Potatoes*), F617 (*Enclosed Wheat Field with Reaper and Sun*), F659 (*The Garden of Saint-Paul Hospital*), F671 and F770 (*Landscape with the Chateau of Auvers at Sunset*). The convention here has warp threads oriented vertically. To depict weave matches, paintings may need to be rotated to conform to this convention. The catalog labels on the weave maps indicates the "up" direction for the painting. These paintings were placed side-by-side to minimize vertical size of the graphic, *not* because they matched in weft. In fact, none of these paintings matched each other in the weft direction.

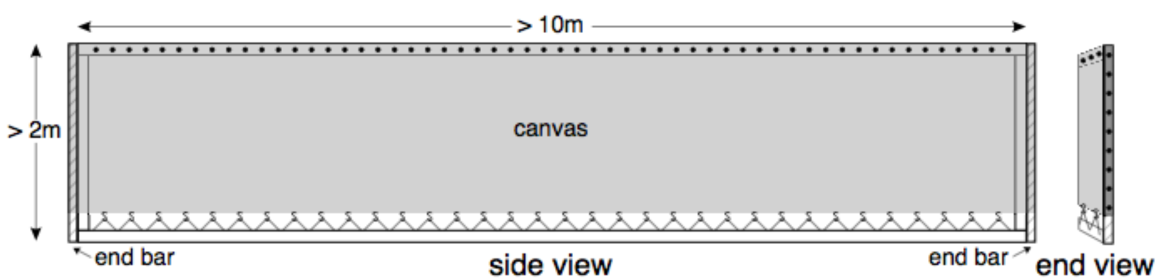

Figure 3. Schematic representation of a commercial priming frame. The black dots represent spikes. Note that the bottom edge is stretched with a hook-and-lace mechanism.

Endnotes

[1] Van Gogh preferred 5 or 10m rolls of “ordinaire”-grade canvas obtained from the Paris colorman Tasset et L’Hôte.

[2] By convention, the threads along the long direction of a canvas roll are the warp threads and the short-direction threads running across a roll the weft threads.

[3] We must make sure that the x-ray-wide thread counts agree sufficiently because two deviation maps could agree even though the average thread count subtracted from the weave maps to produce them do not agree. In fact, we have found that such false agreements do occur.

[4] For example, see letters 593, 629, 631, 680, 687, 689, 691, 699, 758, 777, 800, 808, 823 and 863, 874 from February 2, 1888 to May 21, 1890 (Jansen et al. 2009). Occasionally, other lengths were ordered (one time 20m but not from Tasset) and van Gogh made use of local canvas suppliers.

[5] The authors are indebted to Philippe Huyvaert, President of nv Claessens sa, for devoting his time for a tour of his operations and answering our questions about his manufacturing practices. The company is exceptional for its knowledge and skills concerning traditional hand methods of preparing artist canvas, which it still practices there today.

[6] These findings agree with what we see in the angle maps of van Gogh’s paintings on Tasset et L’Hôte canvas, suggesting that the canvas was indeed stretched in a manner similar to this hook-and-lace system on an upright priming frame and them primed. An alternative commercial practice was to simply nail the four canvas edges at consistent intervals to the sides of a priming frame that had been laid flat on trestles for applying sizing and ground layers. This procedure is used today by the French Company Lefranc Bourgeios (Bomford 1990, 48).

[7] We have found strong weft-thread cusping for two paintings that aligned in weft. Cusping strength, as measured by the size of the thread angle deviation, was much larger than the warp thread cusping introduced by the priming frame. Philippe Huyvaert informed us that cusping occurs in the canvas weaving process due to the initial slackness in the tension of the wound bobbin. Its presence indicates the beginning of a bolt.

[8] We do not know if looms produced bolts having similar manufacturing variations in the warp direction.

[9] The *Sunflower* paintings differ sufficiently in composition that determining which one is being referred to in a letter can be at least partially, if not uniquely, determined.

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