Thread Counting
Its role in technical painting examination and how to obtain thread count results

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"Thread counting" is a term commonly used in technical painting examination. It means measuring the density and orientation of the vertical and horizontal threads that comprise the painting's canvas support. The Thread Count Automation Project (TCAP) developed computer-based techniques for efficiently calculating thread counts from a variety of image types that reveal the canvas underneath the paint. From these measurements, thread counts can be used in a variety of ways. Average thread counts grossly characterize the canvas, allowing a rough determination of whether two paintings' canvas supports are similar or not. Thread-density maps—displays of the vertical and horizontal thread densities everywhere on the painting—more fully characterize the canvas. We have found that thread density varies in an erratic way in the direction perpendicular to the thread direction. For example, the density of horizontal threads is consistent in the horizontal direction but varies unpredictably vertically. Figure 1 illustrates typical thread density maps and shows these stripes.

Thread density patterns differ for the warp and weft threads; those shown in Figure 1 are typical. The warp threads are the vertically oriented thread in a loom; the weft threads are the horizontal threads that are woven between the vertical (warp) threads to produce the cloth. For the example painting, the weft threads are the painting's horizontal threads, the warp threads the vertical ones. With this information, the orientation of the painting's support on the original canvas bolt can be determined.

More important for art historical applications is the remarkable consistency of these thread-density patterns for the entire length (warp threads) and width (weft threads) of the canvas bolt produced by a loom. Because of this consistency, if two supports were cut from the same bolt of canvas in such a way that they "share" threads, their thread-density patterns should agree, resulting in what we call a "match."

The thread-counting software also measures the thread angles everywhere on the painting (Figure 1). The angle maps vividly show cusping, the displacement of threads to the side caused by attaching the canvas at discrete locations to the stretcher/strainer. The horizontal threads along the

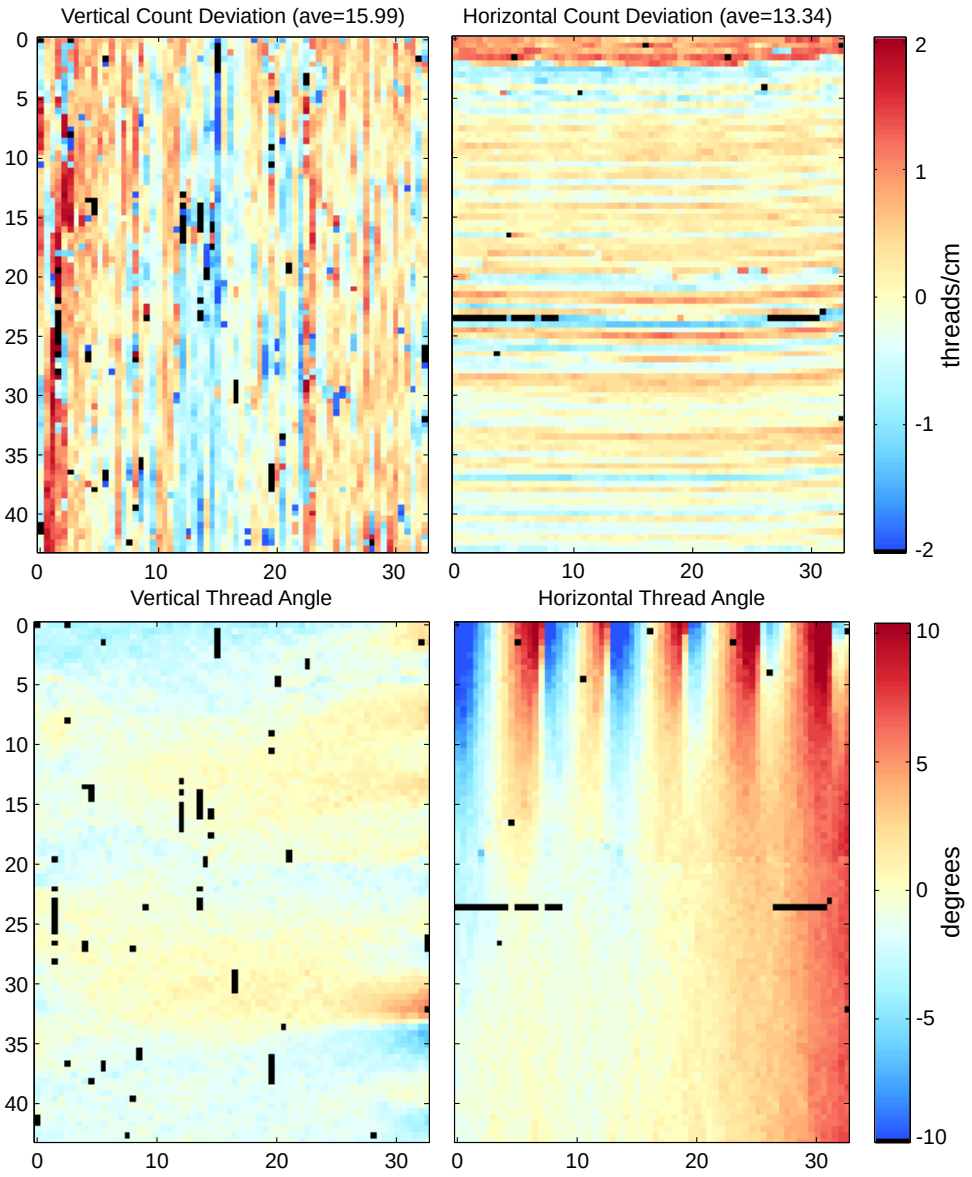

Figure 1: Thread-density and thread-angle maps for van Gogh's painting *Portrait of an old man* (F205). The upper row shows the variation of the vertical and horizontal thread densities about the painting-wide averages every 0.5 cm. Thread angles in degrees are shown in the bottom row. The spatial coordinates are expressed in centimeters.

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painting's top edge have been displaced more than the vertical threads along the right edge. The reason why the opposite side show little cusping indicates that this canvas was starched and prepared with a base layer of paint on a large commercial priming frame. The canvas for this painting was then cut from the larger, commercially prepared canvas roll. If the thread-density patterns match, so should their cusping patterns and what the patterns revealed about the preparation process.

Thread counting and authentication

One might be tempted to say that a thread-density pattern match between two painting's canvases means that they must have been painted by the same artist. Finding that two paintings' canvas supports match (or don't match) does not necessarily mean that the same (or different) artist created the paintings. Because canvas bolts produced by one run of a loom are usually longer than a roll, finding a warp-thread match between two paintings does *not* necessarily mean that the supports came from the same roll; one can only claim they came from the same *bolt*. So, the two matching paintings could have come from different rolls, which could have been separately obtained by different artists. In contrast, a weft-thread match means that the two paintings' supports were originally side-by-side on the same roll. Even if such a thread-density match is found, the same artist may not have painted both: the two canvases could have been mounted on a stretcher by a artist supply merchant and sold to different artists. If no thread-density match is found, it could be that the same artist used two different supports for the two paintings. *A more complete examination of a painting than calculating thread counts would be needed for authentication*. That said, determining thread-density patterns is an important aspect of a technical examination of a painting; but it's not a conclusive one.

Requesting thread counts for paintings

An inquiry about obtaining thread counts for a painting or a set of paintings should be made first. Depending on the project's scope and difficulty, a charge for the image manipulations and thread count calculations may be necessary. Read the image requirements carefully; state the imaging method in the inquiry. Unless a backlog exists, calculations can be completed soon after receipt of the images.

Image requirements

Images suitable for measuring the thread density patterns of a painting's canvas can come from a variety of sources. Requirements for these images are both general and specific to the imaging method. All need to satisfy certain basic requirements.

- A low-resolution color image (photograph) of the painting should be supplied. It will be used to confirm location within the painting and orientation of the images used for thread counting.
- A map of the image locations on the painting would be useful. In some cases, the painting can be discerned from the image; having a layout map helps confirm the image's location. This map can take any of several forms: a low-resolution surface image with image boundaries and identifiers, or even a simple text file having image identifiers arrayed in a way that reflects image layout.
- Images should overlap each other at least by several centimeters on all sides. Edge images should extend past the painting's border by a centimeter or so.

- *Color images for thread counting are not required*; grayscale images suffice. Color images can be processed but only increase file transfer sizes by a factor of three; we remove color information during pre-processing.

- The image scale must be known: how does distance on the image correspond to distance on the canvas? Without this information, thread count measurements, expressed in threads/cm, will not correspond to the actual thread count but rather to the image's. Without a one-to-one scaling, finding thread-density pattern matches among paintings is impossible.

- Assuming a one-to-one image — one centimeter on the image corresponds to one centimeter on the canvas, the sampling density should be at least 300 dpi. The software can cope with higher densities, but anything higher than 600 dpi will not improve thread count results, assuming the thread count is not too high (less than 50 threads/cm). However, densities less than a 300 dpi can cause inaccurate counts; the lower the resolution, the more the count accuracy degrades.

- The number of bits per pixel must be at least eight. A larger number of bits does not improve the results but can be accepted by the software.

Detailed requirements apply to each imaging methodology. Regardless of the imaging method, the file format should be TIF with no compression. Satisfying these requirements makes forming a single composite image much easier.[1] We have experience with all of the following imaging methods.

Scanned x-ray films. Images acquired by scanning x-ray films with a digital scanner is the most common method of digitization. However, a special scanner, one with a transparency-scanning capability, is required. If the film is larger than the scanner's surface, several scans will be needed to digitize the entire film. The film can be oriented in different ways to achieve full coverage.

Direct digital x-rays. Current technology can satisfy the resolution requirement given above. A 100 μm dot radius corresponds to a scan resolution of 254 dpi. Smaller (larger) dot radius increases (decreases) the resolution proportionally. Achieving the required resolution of at least 300 dpi requires a spot size smaller than 85 μm.

However, only recent digital x-ray systems produce one-to-one images. The greater the distance between the imaging surface and the painting surface, the greater the disparity between physical distance on the painting and distance inferred from the image. The imaging surface (sensor) must be placed close to the painting surface to mitigate scaling issues. It is not the image resolution, but the final resolution after scaling to physical distance that matters in thread counting. Scale disparity can be corrected by providing the measured distance between landmarks in the painting that are visible in the x-ray. Even the knowing the widths of

[1] A single image revealing the canvas yields better thread count results.

stretcher bars visible in the x-ray (or the distance between them) can be used to scale the x-ray image. Note: *The more the imaged needs to be scaled because of painting-sensor separation, the lower the physical resolution from that provided by the digital x-ray system.*

Verso photographs. Assuming the painting has not been relined, verso photographs can be processed to reveal the thread counts with the same software that processes scanned x-rays. What verso photographs cannot reveal is what is underneath the stretcher and the crossbars. Consequently, cusping may not be present in the processed results. With this caveat, photographs are typically cheaper and easier to obtain than x-rays.

That said, care must be taken in snapping the photographs. Raking light reveals the canvas threads more than behind-the-camera lighting, but should be at about a 45° angle to the threads. The reason for this setup is that light shining parallel to the thread direction won't reveal the threads. Also, in raking light, brightness will vary across the canvas, getting dimmer the further the distance from the light source. Such gradations can usually be removed with image processing software, but not if the canvas weave cannot be seen in the brightest or dimmest portions of the photograph.

The painting and the camera's image plane *must* be parallel (for example, both should be vertical) and the camera must be close enough to visualize the canvas threads. Photographs should be uncompressed by the camera, saved in the largest file-size format available. Several photographs might be needed to cover the canvas; overlapping pictures are essential. But as explained earlier for digital x-rays, the physical scale must be known. For *each* photograph to be processed, a second should be taken without moving the painting or the camera that shows a ruler placed on the canvas surface. Both should be sent for thread counting.

Recto photographs. If the artist used a light brushstroke, the canvas threads could be visible to the naked eye, especially in raking light. In such cases, photographs taken in the same manner as verso ones — several photographs to cover the surface, each of which is accompanied by a physical-scale photograph — can be processed for thread counting. In contrast with verso photographs, cusping can be determined with recto photographs.

However, light conditions matter more than for photographs of the verso. The same raking light conditions and considerations should be followed. Success can be judged by inspecting the recto surface photographs for the canvas weave in a graphics editor. Some portions of the canvas may be obscured by the impasto. The thread count software can accomodate such situations.

Sending the files

Once the images for thread counting, a surface image and a layout have been collected, they can be sent by a variety of electronic methods. Both Dropbox (`dropbox.com`) and WeTransfer (`wetransfer.com`) have proven very useful.

- Dropbox supports cloud storage and the capability of providing a link to the folder containing the information. E-mailing the link to TCAP allows download access.
- WeTransfer is a file transport system. One uploads the files and provides the e-mail addresses of the recipients. Up to 2 GB can be sent for free.

Thread count reports

A thread count report will be provided. The reports or the provided images are not made public unless permission is obtained. If the artist is known, thread-density pattern matches with the artist's works and his/her contemporaries will be reported. As with thread count reports, any matches or lack of a match are not made public without permission. We retain the images but won't release them; we want to use images from a wide variety of paintings to improve thread-counting algorithms.