THREAD
COUNT
AUTOMATION
PROJECT

TCAP Team

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The Thread Count Automation Project (TCAP), initiated in 2007,
is dedicated to creating and disseminating
computer-assisted, signal-processing-based tools
that support conservators and art historians
in their examination and analysis of fine art,
in particular paintings on canvas.

1 Overview

In 2010 the number and range of paintings counted by TCAP exploded across artist and painting period, amounting to almost 3000 x-rays. As an indication of the breadth of activity in preparing thread count reports consider Table 1 (page 2), which lists all of the paintings TCAP has examined, the majority of which were conducted in 2010.

We have prepared thread count reports on over 300 paintings by Vincent van Gogh, which is over half those in museums worldwide. For five artists — Vermeer, Matisse, Monet, Renoir, and Rembrandt — we have examined 10 or more paintings by each. These artists represent the major projects actively pursued by the Thread Count Automation Project (TCAP) in 2010:

- Vincent van Gogh: thread counts for all paintings in conjunction with the studio practice project of the Van Gogh Museum
- Johannes Vermeer: a project initiated by TCAP to count paintings by Vermeer and his Delft School contemporaries
- Henri Matisse: part of the technical examinations for the exhibition "Matisse: Radical Invention 1913-1917" held in 2010 at the Art Institute of Chicago and the Museum of Modern Art
- Claude Monet and Pierre-Auguste Renoir: in support of an on-line cataloging effort for the impressionist painters in the collection of the Art Institute of Chicago
- Rembrandt van Rijn: begun in collaboration with a pilot project conducted by the Mauritshuis, the Rijksmuseum, and the RKD and now connected to the study of Rembrandt and his pupils being conducted by the Rijksmuseum

Our contributions to these projects are documented primarily in thread count reports and weave match reports on successful searches for weave matches.

The TCAP team was expanded in 2010 with the addition of Professor Robert G. Erdmann from the University of Arizona. Rob adds his self-developed sophisticated software suite for x-ray stitching to our toolkit for automated examination of paintings on canvas. All of our thread count reports in currently active and future projects utilize a composite stitched x-ray. Rob's research in using image processing to analyze the microstructure of materials from digital images should translate into useful background for canvas x-ray texture classification for rollmates without shared threads, which is a major algorithm development topic for TCAP in 2011.

2 Weave Matches

The most significant advances this year were in our search for weave matches signifying rollmates.

As our collection of scanned x-rays grows, in particular for the Van Gogh Project, the cliques of paintings with a strong weave match to at least one other member of the clique have grown. Over half of Van Gogh's paintings have a match with another Van Gogh painting. Our weave matches have added art historical insight in a number of cases, including, for example:

artist	number of paintings	number of x-rays	number of paintings with matches
van Gogh and contemporaries			
van Gogh	317	1300	182
Bernard	5	16	–
Degas	1	4	–
Gauguin	7	40	2[a]
Laval	1	6	–
Toulouse-Lautrec	1	4	–
Schuffenecker	1	8	–
Signac	1	4	–
van der Weele	1	8	–
van Rappard	4	9	–
Vermeer and contemporaries			
Vermeer	21	186	4
van der Burch	1	8	–
de Hooch	8	48	–
de Man	1	8	–
van Vliet	1	7	–
Rembrandt and contemporaries			
Rembrandt	10	139	–
Flinck	2	39	–
Early Netherlandish artists			
Bouts	4	47	2
van der Goes	5	9	–
Impressionists			
Monet	24	200	14
Renoir	17	99	–
Individual artist studies			
Cagnacci	1	1	–
El Greco	3	40	–
Jordaens	1	48	–
Lane & Mellen	4	9	–
Lievens	2	25	–
Matisse	22	492	5
Meléndez	4	8	–
Munch	1	22	–
Titian	1	4	–
Velázquez	4	55	2
TOTAL	482	2893	211

[a]Match with paintings by van Gogh

Table 1: Paintings Examined

- DATING VISIBLE COMPOSITIONS :: Weft alignment of F659 and F607 supports shift in dating of F607 from 1888 to late 1889.
- DATING UNDERLYING COMPOSITIONS :: Canvas weave match supports claim of F297a and F275 as being cut from adjacent positions in the same roll. This supports the idea that their underlying pictures are both Nuenen period studies of peasant heads.
- ATTRIBUTION ISSUES :: Identification of *Le moulin blute fin* as being on canvas from same manufacturer as that used for F215d due to similarity of weave (average and range) as well as ground layer and canvas stamp from Rey et Perrot shop supports attribution of this painting to Van Gogh.
- TRIPTYCH GROUPINGS :: Weave matches provide new evidence to reconsider the triptych grouping of "Sunflower" and "Berceuse" and to confirm the grouping of several other paintings into triptychs.
- SEQUENCE OF EXECUTION OF SERIAL PAINTINGS :: Thread counts and weave maps provide supporting evidence to determine sequence in which Millet copies were executed, in particular that they fall into two groups on different types of ready-primed canvas.

This analysis of the implications of the large number of weave matches we have discovered among Van Gogh's paintings will continue in 2011, when Rick and Don will be frequent visitors to Amsterdam to participate fully in the Van Gogh Museum's studio practice project.

We are also spotting weave matches for artists dating back to the 15th century. We have prepared a document highlighting a variety of these matches that can be downloaded from `http://people.ece.cornell.edu/johnson/wmg/gallery.pdf`. Several of the matches discovered for other artists were suspected. For example, the weave match between a certified Vermeer (in the Louvre) and the most recently "discovered" Vermeer had been predicted. In addition, examining the three paintings in a triptych attributed to Dirk Bouts showed a side-by-side match between two of them.

A major gap in our ability to identify rollmates is the pairing of canvases that share no threads, and therefore have no weave match, but were cut from the same roll. Here rollmate candidate designation relies on discerning texture similarity for compatibly acquired x-rays. Developing algorithms for automatic texture similarity classification will be a task for TCAP in 2011.

3 Major Projects

Counting van Gogh. In coordination with a studio practice project underway at the Van Gogh Museum (`http://www3.vangoghmuseum.nl/vgm/index.jsp?page=13321&lang=en`), TCAP, in collaboration with Dr. Ella Hendriks (Head, Conservation Department, Van Gogh Museum), significantly broadened our database of paintings by van Gogh analyzed with our thread counting software. TCAP has counted over 317 paintings (some of these have a questionable attribution) and has begun assembling a growing collection of sub-groups of rollmate candidates with "matching" patterns of varying local thread density. A total of thirty match cliques have been identified that contain 182 paintings by van Gogh and two by Gauguin. One clique consists of 47 paintings, which prompted us to examine in more detail to what extent a weave match implies a canvas roll match. We have also begun using Rob Erdmann's automated mosaicking software to

create master x-rays for paintings in match cliques. We have found that weave patterns computed from these produce more reliable weave matches, reducing the number of false matches.

All of this thread count data, and other data, such as ground materials assessment, critical to rollmate status evaluation, is to be archived by the end of 2010 in the studio practice project of the Van Gogh Museum. Beginning in 2011, the museum study staff will complete and examine this collection of data with specific attention to rollmate possibilities and dating issues. A major activity for TCAP in 2011 will be to help interpret the implications of clique membership and non-membership. Preliminary results indicate that the automatically generated expansive thread count data will advance the investigations in a variety of issues in van Gogh studies. Indeed, some parts of the general understanding of either Vincent's studio practice or the procedures followed by canvas manufacturers will require re-thinking to achieve consistency with the forensic data being generated.

Rembrandt and pupils. The Rembrandt paintings study begun in 2009 revealed a quite substantial non-uniformity in the thread thickness (apparent in the x-rays). This challenged the robustness of our current algorithms. Two alternatives were pursued (and will be followed into 2011): (i) adding a pre-calculation triage component to our current scheme that removes examination squares with unreliable data from being counted and (ii) upgrading our algorithms to accommodate more weave non-uniformity. Once these algorithmic efforts have been completed, the software should be capable of producing weave patterns for paintings from x-rays for any period.

Despite the varying regularity in thread density in Rembrandt's canvases, the thread direction remains quite uniform within small evaluation squares across the canvas. Thus, our current algorithms are quite suited to constructing angle maps for paintings by Rembrandt. These angle maps provide vivid display of cusping allowing a more precise and more generally acceptable quantification of cusping depth, which is a key factor in analyzing a canvas that has been cut down from its original size. Late in 2010, TCAP began assembling an archive of such weave angle maps for Rembrandt paintings. This activity will grow in 2011.

The range of contemporaries to be examined will grow in 2011 as TCAP assists in a major study of paintings by Rembrandt and his pupils in which the Rijksmuseum is participating.

Counting Vermeer and the Delft School. At the close of 2009, TCAP established a project with the goal of counting threads for all Vermeer paintings on canvas. Currently, we have analyzed twenty-one of the thirty-three extant paintings by Vermeer on canvas. We want to extend the study to Vermeer's seventeenth-century Delft School contemporaries that used regularly woven canvas supports as did Vermeer. This work found a previously unnoticed weave anomaly: the thread angle maps not only reveal the presence and strength of cusping, but also an occasional unevenness of weft thread direction. Here, a narrow band of weft (never warp) threads appear to be wandering across the canvas rather than running straight across. This weave anomaly has been seen in many paintings we have examined from the sixteenth and seventeenth centuries but never in our corpus of van Gogh paintings. We want to understand how this effect occurs in the weaving process. Also, its presence apparently helps in the identification of warp/weft thread directions.

Late 19th and early 20th century French painters. During 2009, TCAP prepared thread count reports for paintings on canvas by Henri Matisse to be included in a forthcoming exhibition jointly created by the Art Institute of Chicago and the Museum of Modern Art in New York City. The exhibition was held sequentially at the two museums in 2010. TCAP continues to provide thread count reports on a regular basis for Renoir and Monet paintings, helping create technical content for an on-line catalog to be created by the Art Institute of Chicago.

4 Limited Investigations

Museums and galleries that contacted TCAP with requests on specific paintings to which TCAP responded with thread count reports in 2010 include:

- Kunsthistorisches Museum: examination of a fragmented painting by Titian
- Gemäldegalerie Kassel: a painting by Jordaens
- Museum of Fine Arts, Boston: two paintings by Fitz Hugh Lane and two paintings by his student Mary Mellen
- Frick Collection and the Metropolitan Museum of Art: four paintings by Velázquez

Academic art historians also approach TCAP regarding specific focused issues, some of which blossom into a substantitve collaboration, such as in 2010:

- Early Netherlandish paintings: a collaboration with Professor Diane Wolfthal (Rice) to explore diptychs and triptychs for weave matches

5 Publications

Available at `http://people.ece.cornell.edu/johnson/` and/or `http://www.ece.rice.edu/~dhj`.

- D. H. Johnson, L. Sun, C. R. Johnson, Jr., and E. Hendriks, "Matching Canvas Weave Patterns from Processing X-Ray Images of Master Paintings," *Proc. 35th Int. Conf. on Acoustics, Speech, and Signal Processing*, Dallas, TX, March 2010.
- D. H. Johnson, E. Hendriks, M. Geldof, and C. R. Johnson, Jr., "Do Weave Matches Imply Canvas Roll Matches?," *38th Annual Meeting of American Institute for Conservation of Historic and Artistic Works*, Milwaukee, WI, May 2010.
- E. Hendriks, D. H. Johnson, and C. R. Johnson, Jr., "Interpreting Canvas Weave Matches," *TCAP Technical Report*, May 2010. [Submitted to *Art Matters*.]
- C. R. Johnson, Jr., D. H. Johnson, N. Hamashima, H. S. Yang, and E. Hendriks, "On the Utility of Spectral-Maximum-Based Automated Thread Counting from X-Rays of Paintings on Canvas," *TCAP Technical Report*, June 2010. [Submitted to *Studies in Conservation*.]

- D. H. Johnson, C. R. Johnson, Jr., and E. Hendriks, "Signal Processing and Analyzing Works of Art," *Proc. SPIE (Applications of Digital Image Processing XXXIII)*, vol. 7798, San Diego, CA, August 2010.

6 Presentations

Several (unpublished) talks about TCAP efforts were given in 2010.

- **D. Johnson**, "Automatic Thread Counting and Weave Matching," Conservation Department, Museum of Fine Arts, Houston, January 6, 2010.
- **R. Johnson**, "Adventures in Thread Counting: Van Gogh Weave Match Hunt," Shell Quarterly Review, Van Gogh Museum, March 23, 2010.
- **D. Johnson**, "Signal Processing and Analyzing Works of Art," *Sparsity Conference*, Vrije Universitet Brussels, April 6, 2010.
- **R. Johnson**, "Adventures in Thread Counting: Matisse Weave Match Hunt," Matisse Study Day, Art Institute of Chicago, April 6, 2010.
- **D. Johnson**, May 27: "Do Weave Matches Imply Canvas Roll Matches?" *Workshop on Image Processing for Artist Identification III*, Museum of Modern Art, May 27, 2010.
- **R. Johnson**, "Vermeer and the Delft School Thread Counting Project: Progress Report, " Rijksmuseum, June 23, 2010.
- **R. Johnson**, "Weave Maps and Matches," Conservation Department, Guggenheim Museum, October 22, 2010.
- **R. Johnson**, "Counting Van Gogh: Applying Digital Signal Processing to Painting Analysis," Center for Signal and Image Processing, Georgia Institute of Technology, November 18, 2010.

7 Personnel

Cornell University:
Rick Johnson
Harold Figueroa
Xioafeng Gu (fall '10)
Naoto Hamashima (spring '10)
Vikram Rao (spring '10)
Jose Rosello (fall '10)
Harold Yang (spring '10)

Rice University:
Don Johnson
Stephen Crowe (spring '10)

University of Arizona
Rob Erdmann

8 Principal Collaborators among art historians and conservators

Ella Hendriks (Van Gogh Museum)
Chris Stolwijk (Van Gogh Museum)
Louis van Tilborgh (Van Gogh Museum)
Kathrin Pilz (Van Gogh Museum)
Frans Stive (Van Gogh Museum)
Teio Meedendorp (Van Gogh Museum)
Muriel Geldof (Instituut Collectie Nederland)
Petria Noble (Koninklijk Kabinet van Schilderijen Mauritshuis)
Michiel Franken (Rijksbureau voor Kunsthistorische Documentatie)
Wietske Donkersloot (Rijksbureau voor Kunsthistorische Documentatie)
Ige Verslype (Rijksmuseum)
Robert van Langh (Rijksmuseum)
Gregor Weber (Rijksmuseum)
Elke Oberthaler (Kunsthistorisches Museum)
Sabine Pénot (Kunsthistorisches Museum)
Charlotte Hale (Metropolitan Museum of Art)
Walter Liedtke (Metropolitan Museum of Art)
Michael Gallagher (Metropolitan Museum of Art)
Sarah Fisher (National Gallery of Art - DC)
Melanie Gifford (National Gallery of Art - DC)
Ann Hoenigswald (National Gallery of Art - DC)
Catherine Metzger (National Gallery of Art - DC)
Arthur Wheelock (National Gallery of Art - DC)
Jim Coddington (Museum of Modern Art)
Kristin Lister (Art Institute of Chicago)
Frank Zuccari (Art Institute of Chicago)
Inge Fielder (Art Institute of Chicago)
Kelly Keegan (Art Institute of Chicago)
Kimberly Muir (Art Institute of Chicago)
Johanna Salvant (Centre de recherche et de restauration des musées de France)
Michel Menu (Centre de recherche et de restauration des musées de France)
Meta Chavannes (Kröller-Müller Museum)
Luuk van der Loeff (Kröller-Müller Museum)
Sjraar van Heugten (Independent art historian)
Colin Bailey (Frick Collection)
Joseph Godla (Frick Collection)
Pablo Perez d'Ors (formerly Frick Collection)
Blaise Ducos (Musée du Louvre)
Dominique Surh (Leiden Gallery)
Larry Keith (National Gallery, London)
Betsy Wieseman (National Gallery, London)
Diane Wolfthal (Rice University)