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

With multiple visits to the Netherlands by the TCAP Team in the first half of 2011 (funded in part by travel grants from the US National Science Foundation (NSF), the Netherlands Organization for Scientific Research (NWO), and the Netherlands Institute of Advanced Study (NIAS) in the Humanities and Social Sciences), the level of TCAP activity has expanded significantly. The range of paintings counted by TCAP includes more than 40 artists covering over 4 centuries, comprising a collection of over 3800 x-rays. As an indication of the breadth of TCAP activity in preparing thread count reports consider the following table, which lists all of the paintings TCAP has examined, since its inception.

PAINTINGS EXAMINED

artist	number of paintings	number of x-rays	number of paintings with matches
van Gogh and contemporaries			
van Gogh	394	1638	237
Bernard	6	20	1[1]
Gauguin	7	40	2[2]
Laval	1	6	–
Mourier-Petersen	2	6	–
Russell	1	4	–
Toulouse-Lautrec	1	4	–
Schuffenecker	1	8	–
Signac	4	16	–
van der Weele	1	8	–
van Rappard	4	9	–
Vermeer and contemporaries			
Vermeer	24	224	6
van der Burch	1	8	–
de Hooch	8	48	–
de Man	1	8	–
van Vliet	1	7	–
Rembrandt and contemporaries			
Rembrandt	10	139	–
Bol	1	6	–
de Lairesse	3	63	–
Farinati	1	21	–
Flinck	2	39	–
van Everdingen	2	21	–
Early Netherlandish artists			
Bouts	4	49	2
van der Goes	5	9	–

[1] Match with paintings by van Gogh
[2] Match with paintings by van Gogh

(unknown)	1	8	–
Impressionists			
Degas	1	4	–
Manet	2	42	–
Monet	41	334	18
Pissarro	2	8	–
Renoir	18	111	–
Individual artist studies			
Cagnacci	1	1	–
El Greco	3	40	–
Guardi	1	1	–
Jordaens	3	142	–
Hodges	1	5	–
Lane & Mellen	4	9	–
Lievens	2	25	–
Matisse	22	492	5
Meléndez	4	8	–
Modigliani	2	8	2
Moran	1	9	–
Munch	1	22	–
Tintoretto	1	4	–
Titian	3	49	–
Velázquez	4	55	2
Subject studies			
Doctors	4	26	2
TOTAL	608	3807	274

We have prepared thread count reports on over 390 paintings by Vincent van Gogh. For 5 other artists — Vermeer, Matisse, Monet, Renoir, and Rembrandt — we have examined 10 or more paintings by each. For a significant number of paintings we have found weave matches. Approximately 60% of the paintings by van Gogh we have counted have weave matches with another van Gogh painting we have counted. For a sample weave match report, including an image of the convincing alignment of the striped patterns in the weave density maps for 2 paintings, see *http://people.ece.cornell.edu/johnson/mr_F651-659.pdf*. Our weave match search has been greatly facitlitated this year with our present procedure of careful multi-scale stitching of a composite x-ray from the individual x-ray films prior to automated thread counting. The testing for a similarly patterened weave is more precise from a single composite x-ray than from a collection of separate weave maps for each x-ray film.

As indicated by the table of paintings examined, we organize our archives, and to a great extent our projects, around separate artists, and co-operating museums. Most of our projects are in collaboration with museum exhibitions and catalogs. Our current active projects include

- *Van Gogh*: Studio Practice Project and Roll Layout Project (Van Gogh Museum)
- *Vermeer and the Delft School*: Thread Count Project (Rijksmuseum, Metropolitan Museum of Art, Mauritshuis, Kunsthistorisches Museum, National Gallery of Art - Washington, and

Frick Collection)

- *Rembrandt and Pupils*: Studio Practice Evolution Evaluation Project (Rijksmuseum, University of Amsterdam, and Netherlands Cultural Heritage Agency)
- *French Impressionists / Monet and Renoir*: On-Line Catalog Project (Art Institute of Chicago)
- *Rembrandt*: Weave Angle Map Archive Project (RKD, Rijksmuseum, and Mauritshuis)
- *Titian*: Exhibition (Kunsthistorisches Museum)

Projects planned but not yet launched include

- *Renoir*: Exhibition (Frick Collection)

Projects currently under contemplation include

- *Frans Hals*: Regents Group Portraits (Frans Hals Museum and RKD)
- *Reynolds*: Exhibition (National Gallery - London and Wallace Collection)
- *Steen*: Catalog (Mauritshuis)

In all of these projects, TCAP is involved in various phases of the collection and utilization of automated thread count data, including (i) image processing algorithm development, refinement, and implementation, (ii) interpretation of automated canvas examination in terms of studio practice, and (iii) development of interpretation of impact of count data on various art historical issues. The last item has grown as a fraction of TCAP's activities as the active projects have matured. It is in this phase that the TCAP team is likely to encounter new challenges to image-processing-based analysis of paintings beyond thread counting that are suited to the TCAP's skill set.

The table implies (with presumption of a 3-year history of thread count report preparation by TCAP) an annual thread counting capacity for TCAP of approximately 200 paintings composed of less than 7 x-rays each on average. The growth in effort with activation of the projects under contemplation and the development of new tools demanded by a growing range of art historical issues, requires a reduction in this counting rate or an unforeseen near-term increase in the size of the TCAP Team.

Brief summaries follow for the active projects.

1.1 Van Gogh Studio Practice Project

With the first half of 2011 representing the period of scientific data collection for the studio practice project, TCAP has provided its thread count and weave match reports. TCAP is committed to preparing a description of automated thread counting as a "chapter" in the issue of *Van Gogh Studies* devoted to the Van Gogh Museum's Studio Practice Project, as well as two essays in the exhibition catalog: one describing the thread counting tool with an outline of the types of questions for which it is useful and the other detailing the new findings made for particular case studies in the project.

1.2 Van Gogh Roll Layout Project

TCAP's goal of counting, and hunting for weave matches among, as many as possible of the world's Van Gogh paintings on canvas was the source of its dominant activity in the first half of 2011. The format and content of TCAP's reports was debated and became more standardized in the first half of 2011.

But, during the first half of 2011, the emphasis of TCAP activity began to shift from a weave match hunt to the more ambitious goal of solving roll layout puzzles using a combination of weave density map matches, cusping and other angle map features, other physical data (such as selvedge existence, size and ground layers composition, and stretching method) when available, and dating drawn from Van Gogh's letters and stylistic analysis.

As the dataset of counted Van Gogh paintings approached 400 in the first half of 2011, thanks to Vincent's practice of purchasing much of his canvas by the roll, implications of TCAP's thread count and weave match reports for dating and ordering Van Gogh's paintings, and regarding his studio practice, have expanded signficantly. Some art historical advances relying on TCAP's weave maps were reported in the new catalog of Van Gogh's paintings in Antwerp and Paris published in the first half of 2011.

With the emergence of the Roll Layout Project, a new urgency has appeared in the desire to acquire x-ray data for as many of Van Gogh's paintings as possible. A procedure will be developed and adopted in the latter half of 2011 for continued, gradual enlargement of the project's collection of thread count reports and continued upgrading of affected weave match reports.

As the pace of "new" paintings by Van Gogh to be counted slows and the studio practice project moves into its publication creation phase, the roll layout project will become a dominant activity by TCAP in the latter half of 2011 and in 2012.

1.3 Vermeer and the Delft School Thread Count Project

TCAP has counted the threads in 24 paintings on canvas by Vermeer. Access to scanned x-ray data has been arranged for 29 of the 33 Vermeer's on canvas. Access to the other 4 is still being sought. Three weave-matching pairs of Vermeer paintings have been discovered so far. These weave matches resulted in a manuscript co-authored with Walter Liedtke (Metropolitan Museum of Art) that has been submitted to the Burlington Magazine. This submission on a Vermeer match was coordinated with co-authored submissions to the Burlington Magazine on a Bouts match and a Velázquez match.

1.4 Rembrandt's Pupils Project

In the first half of 2011, TCAP prepared thread count reports for a few paintings by a few of Rembrandt's pupils. This exercise established that the canvas x-ray images were of sufficient quality to support reliable automated spectral-based thread counting (despite a number of Rembrandt's canvases being sufficiently irregular or providing poor x-ray image quality). The art historical issue driving the project is to establish some understanding of how, and to what degree, Rembrandt's pupils adopted and abandoned Rembrandt's studio practices.

1.5 Monet and Renoir On-Line Catalog Project

Thread Count Reports have been prepared for nearly all of the paintings under consideration. Catalog entries debut for a small group in fall 2011, with full catalog launch in 2014. Beginning in 2012, TCAP team will attend an annual scientific exchange meeting on project content at the Art Institute of Chicago.

1.6 Rembrandt Weave Angle Map Archive Project

X-rays will be provided by the Rembrandt Research Project at the RKD for approximately 100 paintings by Rembrandt that may have been altered in size since the painting was completed by the artist. TCAP's weave angle maps provide vivid quantification of cusping, which is a key forensic in estimating canvas size changes. This project is the exploratory exercise in establishing procedures for transferring TCAP's reports to the archives of the RKD.

1.7 Titian Project

The project covers about two dozen paintings by Titian being gathered into a single exhibition. The principal scientific interest to TCAP is that Titian used a variety of weaves, including simple, twill, herringbone, and diamond. This project offers TCAP the opportunity to expand its spectral methods to a wider range of weaves than found in the works of other artists studied by by TCAP.

2 Management Progression

For a description of the development of TCAP since its inception in 2007 until TCAP produced its first annual report (for 2009), refer to the first annual report at *http://people.ece.cornell.edu/johnson/TCAPAnnRep09.pdf*. The 2010 annual report from TCAP can be found at *http://people.ece.cornell.edu/johnson/annrep10.pdf*.

The following listing of TCAP's management progression reflects the metamorphosis related in these annual reports as well as the need to enlarge the team and to arrange for the survivability of this technology that promises to become a fundamental tool in canvas examination in technical art history.

- Rick Johnson :: TCAP Founding Director :: 2007-2009
- Rick Johnson and Don Johnson :: TCAP Co-directors :: 2009-2010
- Rick Johnson, Don Johnson, and Rob Erdmann :: TCAP Team :: 2010 - 2013
- Rob Erdmann :: TCAP Director :: 2013 ...

As the number and range of projects grows, TCAP has decided that rather than have the full TCAP team participate in every project, each project will have a single TCAP team member identified as managing all aspects of that project, with a second team member providing technical support as desired. For the projects listed above, the responsible parties are

Van Gogh Studio Practice Project / Don Johnson
Van Gogh Roll Layout Project / Don Johnson
Vermeer and the Delft School Thread Count Project / Rick Johnson

Rembrandt's Pupils Project / Rick Johnson
Monet and Renoir On-Line Catalog Project / Don Johnson
Rembrandt Weave Angle Map Archive Project / Rick Johnson
Titian Project / Don Johnson
Renoir Exhibition Project / Rob Erdmann
Frans Hals Regents Group Portraits Project / Rob Erdmann
Reynolds Exhibition Project / Rob Erdmann
Steen Project / Rick Johnson

3 Discoveries

Our discoveries can be divided into two categories: those found by design and those found by accident. For TCAP, the first category includes the correlation of striped weave density map patterns to discover weave match candidates.

Despite the breadth of utility of weave density maps, which were the original focus as the product of the automated thread counting software, the accidental discoveries – that always arise with scientific investigation in a fertile field such as this one – have been even more gratifying. The chance creation of weave angle maps and their quickly recognized utility by TCAP's conservator-collaborators in cusping depth quantification resulted in their addition to the standard thread count reports.

These angle maps have also been recognized as prime detectors of two fabric "flaws" with art historical implications. In one case, the weft angle maps showed a flame-shaped spot of angle deviation from the norm that re-occured in 50 cm intervals in the warp direction. These disruptions in the angle maps were related to the bundling and binding of the single length of raw canvas when shipped to the preparer for application of the ground to 5 and 10 meter segments. They can help determine the ordering along a roll among a group of warp-matched paintings. The second flaw is casued by a loss of uniformity in the slack (by leaving too little) needed to weave the weft threads before closing the gate to press the newest threads against the previously woven fabric. The resulting small drop in tension in the previous handful of weft threads causes them to meander across the fabric, thereby creating what we have labelled a "weft snake". It serves as a fully reliable indicator of weft direction in a fabric in the absence of selvedge. Weft snakes are found in approximately 40% of Vermeer's paintings.

4 Challenges

Our use of thread-counting via a spectral-based method suffers two shortcomings

- Some weaves are insufficiently regular, or for some other reason the canvas x-ray image is of insuffcient quality, for our spectral-based methods to be sufficiently reliable in spot (rather than painting-wide average) counts.
- Weave density map correlation for designating weave match candidates relies on the two candidates in the matching pair sharing enough threads.

TCAP has arranged with the Van Gogh Museum to allow the assembly of data to be shared with academic teams seeking to create image processing algorithms to solve these problems. The

"bad" data challenge will present a set of small (e.g. 2 cm x 2 cm) swatches each centered on a line segment across which a hand count was taken that differs from the spectral-based count for the swatch by more than 1 th/cm in at least one direction.

The lack of shared threads by two excerpts from the same painting or by two weave-matched paintings can be viewed as converting the decision on rollmate status into one of texture classification. For each painting in the challenge dataset a collection of 5 cm x 5 cm square excerpts is taken along the diagonal that have no shared threads with any other segments from the same painting. The paintings sampled all have very similar average thread counts and come from several different weave match cliques composed from their high weave profile correlations. Thus, the excerpts that are on fabric from the same bolt, and therefore presumably of similar texture, are known for this dataset.

Teams are being sought now to participate in these challenges which should commence with the start of the 2011-12 academic year.

5 Education

TCAP believes that the long-term absorption of a new computer-based tool for canvas examination is best achieved by its insertion in the graduate curriciulum in conservation programs.

TCAP has established contact with six programs, and given a seminar/workshop at four of them.

- Art Conservation Department, Buffalo State College, SUNY, Buffalo, NY (*www.buffalostate.edu/depts/artconservation*)
- Conservation Center, Institute of Fine Arts, New York University (*http://www.nyu.edu/gsas/dept/fineart/conservation/index.htm*)
- Department of Art Conservation, Winterthur / University of Delaware, Newark, DE (*http://www.artcons.udel.edu/masters*)
- Stichting Restauratie Atelier Limburg (SRAL), Maastricht, the Netherlands and the University of Amsterdam (*http://www.sral.nl/index.html*)
- Courtauld Institute of Art, University of London, London, United Kingdom (*http://www.courtauld.ac.uk/degreeprogrammes/postgraduate/easels/index.shtml*)
- Heritage Conservation Science Program, University of Arizona, Tucson, AZ (*http://www.mseweb.web.arizona.edu/heritage/index.html*)

The current target is an annual visit to each program to provide up-to-date lecture(s) on automated thread counting and training in using free software (compiled for use with a Windows operating system) facilitating manual thread counting from digitized x-rays of sufficient resolution.

6 Distribution List

- Art Institute of Chicago: Francesca Casadio, Douglas Druick, Inge Fielder, Gloria Groom, Kelly Keegan, Allison Langley, Kristin Lister, Kimberly Muir, Frank Zuccari

- Centre de recherche et de restauration des musées de France: Michel Menu, Johanna Salvant
- Frans Hals Museum: Liesbeth Abraham
- Frick Collection: Colin Bailey, Joseph Godla
- J. Paul Getty Museum: Tiarna Doherty
- Independent art historian(s): Sjraar van Heugten (formerly at Van Gogh Museum), Pablo Perez d'Ors (formerly at Frick Collection)
- Independent conservator(s): Nina Olsson
- Kimbell Art Museum: Claire Barry, Bart Devolder
- Kröller-Müller Museum: Meta Chavannes, Luuk van der Loeff
- Kunsthistorisches Museum: Elke Oberthaler, Sabine Pénot
- Leiden Gallery: Dominique Surh
- Metropolitan Museum of Art: Charlotte Hale, Walter Liedtke, Dorothy Mahon, Michael Gallagher
- Minneapolis Institute of Arts: Sue Canterbury
- Musée du Louvre: Blaise Ducos
- Muses Royaux des Beaux Arte Belgique: Irene Schaudies
- Museum Boijmans Van Beuningen Rotterdam : Jeroen Giltay
- Museum of Fine Arts - Boston: Sandra Kelberlau
- Museum of Fine Arts - Houston: Aniko Bezur, Wynne Phelan
- Museum of Modern Art: Jim Coddington
- National Gallery of Art - DC: John Delaney, Sarah Fisher, Melanie Gifford, Ann Hoenigswald, Doug LaChance, Catherine Metzger, René de la Rie, Arthur Wheelock
- National Gallery of Ireland: Adriaan Waiboer
- National Gallery, London: Larry Keith, Ashok Roy, Betsy Wieseman
- Nelson-Atkins Museum of Art: John Twilley
- Netherlands Cultural Heritage Agency: Muriel Geldof
- Rice University: Diane Wolfthal
- Rijksbureau voor Kunsthistorische Documentatie: Wietske Donkersloot, Michiel Franken

- Rijksmuseum: Jonathan Bikker, Robert van Langh, Erika Smeenk, Gwen Tauber, Ige Verslype, Gregor Weber
- Royal Picture Gallery Mauritshuis: Petria Noble
- University of Amsterdam: Emilie Froment, Magriet van Eikema Hommes, René Lugtigheid
- Van Gogh Museum: Ella Hendriks, Teio Meedendorp, Devi Ormond, Kathrin Pilz, Frans Stive, Chris Stolwijk, Louis van Tilborgh
- Wallace Collection: Alexandra Gent