Special Issue Guest Editorial
A Shift to Image Feature Mining

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Why should signal processors care about problems in cultural heritage?

What can signal processing offer to the world of art scholarship and preservation?

These complementary questions have motivated recent movement in our two communities – one composed of signal processors and the other art experts – to collaborate and to try to focus the technologies of signal processing on underresolved problems of art investigation.

At the start of this century a plenary talk [1] delivered at the 2001 IEEE International Conference on Image Processing divided the subjects of a two decade cross-disciplinary effort between a Paris technical university (ENST) and the French national conservation labs (C2RMF) into two broad categories: (i) Archiving and Consulting and (ii) Picture Processing for the Fine Arts. The first category incorporates image acquisition and database access. The second includes image enhancement and restoration, crack network detection, multisource image fusion, color processing, and geometric analysis. Consider a different division of these topics into three groups: (1) image acquisition, (2) image manipulation, and (3) image feature mining. The topics of research in the 1980s and 1990s described in [1] give stronger attention to the first two of these groups than to the third.

This magazine has recognized previously – with a special section on "Recent Advances in Applications to Visual Cultural Heritage" in its July 2008 issue – the growing interest at the start of this century in the nascent application of signal processing to art investigation. Following a vivid description of a wide range of tasks to be addressed in applying signal processing to the analysis of visual cultural heritage, six papers were grouped by the guest editors [2] into three themes: multispectral imaging, artwork analysis, and three-dimensional digitization and modeling. By our division, this special section exhibits a balanced emphasis on all three groupings of image acquisition, manipulation, and feature mining.

The March 2013 special issue of *Signal Processing* devoted to "Image Processing for Digital Art Work" divides [3] its seven papers into two categories: artwork restoration tools (x-ray fluorescence, crack detection) or art piece analysis procedures (canvas weave analysis, painting stylometry analysis). Here the emphasis according to our grouping has shifted to image feature mining.

A recent plenary talk [4] delivered at the 2014 IEEE International Conference on Acoustics, Speech, and Signal Processing describes three separate tasks in computational art history utilizing signal processing algorithms to match manufactured patterns in art supports. All of these tasks fall in the category of image feature mining.

While early research in applying signal processing to art investigation emphasized image acquisition and image manipulation, various manifestations

of image feature mining have achieved more prominence in the past decade as evidenced by the preceding citations providing successive indicators of the directions being taken in this growing field. The eleven papers in the current special issue include studies of photographic paper classification, ancient coin classification, Mayan epigraphy analysis, 3D color print graph signal processing, laid paper chain line pattern matching, content based image indexing, canvas weave analysis, crack detection for simulated in-painting, painting style characterization, and face recognition in portraits. All of these papers engage to a substantial degree in image feature mining. The need in art history and conservation of locating/classifying/identifying/measuring features in multispectral and multidirectional images of artworks is enormous.

One barrier to entry into this field is access to images of sufficient quality and quantity of art works. Therefore, for this special issue the authors were requested to make the images they processed accessible to other researchers – when possible – in order to stimulate the exploration of new and improved solutions. Most have. With that added boost, we welcome you to the modest beginnings of an emerging field that promises to offer many satisfying challenges and will require specialization of and advances in the tools and techniques of signal processing. To assist you in deciding which of the papers to use as your portal into this new domain with ample low-hanging fruit and many as yet undiscovered puzzles, we offer the following summaries (arranged alphabetically by lead author's last name):

Abry et al.

"Multiscale Anisotropic Texture Analysis and Classification of Photographic Prints" illustrates a fruitful interaction between mathematicians, signal processing experts, art scholars and museum conservators. It proposes to characterize textures of photographic prints using an anisotropic multiscale representation of texture, the Hyperbolic Wavelet Transform. Cepstral distances aimed at ensuring balanced multiscale contributions and spectral clustering are combined to achieve texture classification. For proof of concept, these procedures are first applied to a reference dataset of historic photographic papers that combine several levels of similarity, designed for the "Historic Photographic Paper Challenge" and available at http://www.papertextureid.org/, and second to a large dataset of culturally valuable photographic prints held by the Museum of Modern Art in New York. The characterization and clustering results are interpreted in collaboration with art scholars with an aim toward developing new modes of art historical research and humanities-based collaboration.

Anwar et al.

"Ancient Coin Classification using Reverse Motif Recognition" elaborates on bag-of-visual-words techniques to classify ancient Roman republican coins by incorporating geometric (location, rotation) invariances, relying on Delaunay triangulation. One specificity of the contribution is to use reverse side motifs. The performance of the proposed procedure are assessed by application to 2224 coin images from 3 different collections, representing a diversity of 29 different motifs.

Hu et al.

"Multimedia Analysis and Access to Ancient Maya Epigraphy" consists of an interdisciplinary effort involving jointly epigraphers and computer scientists. Making use of the three most famous ancient codices, the article combines different contributions: First, it proposes a high-quality digitalization and annotation scheme presented in a Digital Multimedia Repository. Second, it designs a glyph retrieval system, that marries geometrical and statistical descriptors. Notably, the benefits of incorporating context information via language statistical models are evaluated. Third, a classification is detailed that aims to identify "diagnostic" features for scholars. Achieved results contribute to shape analysis benchmark datasets and to the study of the Mayan writing system.

Johnson et al.

"Hunting Moldmates Among Rembrandt's Prints" describes two signal processing tasks involving chain lines, characteristic markings on early handmade paper that are visible under soft x-ray illumination. The first task involves locating the chain lines; the second uses patterns of chain lines to identify moldmates (papers made using the

same mold). A collection of Rembrandt's papers is used to answer questions about how straight and how parallel the chain lines are, and the authors apply simple mathematical models to estimate the number of chain lines required to reliably detect moldmates. The collection of images is available for others to study.

Lozes et al.

"PDE-based Graph Signal Processing for 3D Color Points Clouds: Opportunities for Cultural Heritage" presents an interesting graph signal processing approach for 3D point clouds, with clear and relevant applications for cultural heritage. It proposes to solve an inverse problem by embedding into a weighted graph framework the resolution of PDEs from point clouds. It makes explicit the construction of the graphs and the definition of the weights and elaborates on the concepts of regularizations on graphs. Three cultural heritage applications are successfully illustrated: colorization, filtering and representation simplification and inpainting.

Picard et al.

"Challenges in Content Based Image Indexing of Cultural Heritage Collections" considers the problem of automatically indexing and searching the contents of digitized archives. Using publicly available data from the Bibliotheque Nationale de France, the authors highlight the inherent difficulty of the task. For example, a histogram of the number of labels per image contrasts with a histogram of the number of images per label; many of the classes are represented by only a single image. This presents a fundamental limitation on the possibilities of automated classification. The paper considers several different features based on local regions of interest, many of which will be familiar to regular readers of the transactions such as SIFT, HOG, and LBP. The authors focus on an aggregating method called Bag of Visual Words, which allows searching the data base using histograms which are created by assigning each descriptor of the image to its nearest entry in a dictionary. The paper then presents results of applying the methods to automated labeling and search. While the success of the method is limited, the paper points the way towards a pair of important and tricky problems that cry out for further consideration by signal processing experts.

Pizurica et al.

High resolution images of the Ghent Altarpiece have recently been made available publicly, and the paper "Digital Image Processing of the Ghent Altarpiece" reports two explorations of these images. The first looks at the problem of detecting cracks in the painting's surface, and uses novel digital inpainting techniques to simulate the appearance of areas of the altarpiece without those cracks. Of special interest are places where the cracks obscure textual material, where the inpainting may help to improve legibility. The second exploration provides a statistical analysis using spatial histograms to examine the painterly appearance of pearls. Pearls which were overpainted in the modern era show distinctly different properties than those painted in historical times, and the hope is that the spatiograms might be capable of distinguishing pearls painted by different hands in the workshop of Van Eyck. The authors are careful to note that the interpretation of such techniques "needs to be checked by conservators using other examination techniques and linking the evidence by their critical and material skills."

Srinivasan et al.

Face recognition has been an active area of interest in the image-processing community for years, with much of the recent attention focused on entertainment and surveillance applications. Art historians, too, have long been interested in identifying the subjects (or "sitters") in portraits. In "Computerized Face Recognition in Renaissance Portrait Art", the authors consider face recognition for analyzing works of portraiture, which is a particularly challenging problem due to the sparsity of available data. The authors use machine learning techniques, and employ a feature extraction approach that is based on and motivated by the same anthropomorphic features used by Renaissance artists' renderings of sitters. The success of the approach is demonstrated on a variety of Western European art works from the 15th through 18th century, including artists such as Bernini, Algardi, Clouet, and Kneller.

van der Maaten et al.

In the application of signal processing to art historical questions, one the most successful endeavors in recent years is to the analysis of x-rays of the

canvas supports of grand master paintings. Matching the thread density portraits of two canvases suggests that the two paintings arise from the same roll of canvas, and can be used for dating and authentication. In "Automatic Thread-Level Canvas Analysis", the authors present a method that locates the thread crossings for their subsequent counting, rather than estimating their local density via Fourier or autocorrelation methods (as in most previous studies). This has clear advantages in that it can more accurately measure small thread deviations and perhaps provide greater assurance of a neighboring match. But the method is also more specific, more targeted, and requires manual annotations of similar x-ray images in order to tune the parameters. The authors propose overcoming this using a crowd-sourced annotation tool that could create a large data base from which the algorithm could be trained. Several striking results are presented, including matches of canvases by Nicholas Poussin and by Vincent Van Gogh.

van Noord et al.

In attempting to answer questions of attribution, art historians and conservators have increasingly been turning to technological analyses of art works. While not a panacea, such scientific analyses can provide another source of information which enhances the data that informs conservators' opinions about attribution. An image processing-based analysis of visual information in art works is presented in "Discovering the artist's style: Learning visual stylistic features from artworks". The authors present an approach to attribution based on feature learning using deep convolutional neural networks, and they show that their approach achieves an accuracy of more than 70% on works within the publicly-available Rijksmuseum Challenge Dataset. Their approach is also able to suggest the degree to which a given region of a painting is characteristic of the artist; this could be particularly useful in cases where multiple artists may have participated in the creation of the work (e.g. in collaborative efforts between artists, or when the artist's students were involved).

Yang et al.

In "Quantitative Canvas Weave Analysis using 2D Synchrosqueezed Transforms", the authors present a Fourier-based approach to counting threads in canvas from x-radiogrpahs of paintings which uses the *synchrosqueezed transform* to "squeeze" the time-frequency spectrum, thereby arriving at sharper, more pronounced peaks when compared with conventional, windowed Fourier-based approaches. The authors demonstrate their approach on a variety of canvas types, including paintings by van Gogh, Vermeer, and Ryder, as well as the Peruzzi Altarpiece by Giotto di Bondone.

Given the value of an active co-author from the cultural heritage community, authors were encouraged to have a representative on their team, which is the case for most of the papers. Such cross-disciplinary collaborations are difficult. The art expert needs to acquire an appreciation of the range and limitations of the signal processor's tools so useful, viable, novel tasks can be identified and addressed. The signal processors must learn to describe their skills without resorting to the language of mathematics, and to appreciate the intellectual depth of the art expert achieved without direct resort to computational tools. Both sides are facing new ways of thinking and conducting research.

Of course, this all makes the challenge that much more appealing to us. So it goes...

References

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