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# DATA-DRIVEN IMAGE STYLIZATION USING GRAPH-BASED FILTERING

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## ABSTRACT

In this work, we consider the problem of image abstraction and stylization. A graph-based framework is proposed to render real images into painterly-style ones and create a simple stylized format from color images. The goal is to abstract images by simplifying their visual content while preserving edges and emphasizing most of the perceptually important information. To this end, the low-contrast regions of an image are first smoothened using iterative graph filters in both the vertex and spectral domains. The abstracted luminance channel is quantized and sharpened using an iterative high-pass graph filter in the spectral domain. The effectiveness of the proposed graph-based image stylization method is verified through simulations. It is shown that the proposed method can yield significantly better visual quality for stylized images as compared to other existing works.

***Index Terms***— Image stylization, graph signal processing, spectral filtering, vertex filtering.

## 1. INTRODUCTION

In this age of big data, we need to revisit traditional signal processing solutions and extend their applicability to emerging problems with large data sets, a critical problem that typically renders classical signal processing solutions inapplicable of handling properly big-data problems which are of great engineering importance. Recently, graph signal processing has provided a new framework for representing model relations among data samples [1]-[3]. For data-oriented applications, a weighted graph can be identified to capture the similarities between data samples. An image may be represented by associating image pixels with graph nodes and the corresponding graph can be analyzed using newly-defined signal processing techniques [1], [4].

Leveraging the new framework of graph signal processing, we address the problem of image stylization, i.e., synthesizing an artistic cartoon/painterly-like image from a new point of view. In recent years, stylized images in the computer graphics, artistic works, social networks, and entertainment have a significant development [5]. Image abstraction is an image processing problem used to modify the contrast of visually important features in order to stylize and create cartoon-like effects on images. This framework has a wide range of applications, including allowing for artistic data-driven simulations of ink, watercolor and oil paintings and cartoons [5]-[7]. In [8], a framework has been proposed for synthesizing painterly, sketchy, and cartoon-like shadings from videos. In [9] the Canny edge detector and mean-shift filter have been successively combined to obtain a cartoon-style image. In [10], a video stylization method has been proposed to produce coherent cartoon and painterly video styles. In [11], an extension to the difference of Gaussian operator for edge detection has been proposed which results in promising versatile styles such as pencil-shading, pastel and woodcut. In [12], a direction-enhancing edge flow field has been proposed for creating hand-painting style images. While a variety of approaches exist for abstracting images and stylizing them, they fail to provide a unified method when applied to large data sets. Thus, there is still scope for further research and investigation to improve such algorithms.

In this work, in order to address the restrictive nature of existing methods, efficient image abstraction and stylization methods are proposed from the new viewpoint of graph signal processing framework [1], [2], which can handle the practical large-scale data analysis tasks. The proposed method for abstracting images is realized by sequential graph-based filtering, detail removal and sharpening filters. For detail removal, graph filters in both the vertex and spectral domains are proposed to reduce image contrast in low-contrast regions. To obtain stylistic illustrations from color images, the abstracted luminance channel is quantized and contrast in higher contrast regions is increased by iteratively adding a highpass-filtered version of the luminance to its quantized version. Simulation results are carried out to evaluate the effectiveness of the proposed graph-based method in image stylization.

## 2. BACKGROUND

Graph signal processing is an emerging field that offers a framework for applying classical signal processing to signals defined on graphs [2]. Let image $z$ of size $n \times n$ be defined as an intensity function on the vertices $V$ of a weighted graph $G = (V, E, K)$ consisting of a finite set $V$ of vertices (image pixels) and a finite set $E$ of edges with the corresponding weights $k_{pq} \in K$, which denote similarity between vertices

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(pixels) $p$ and $q$ in the graph. The function (intensity) values of the image can be denoted as a vector $z = [z(1), ..., z(n^2)]^T$ obtained by row-ordering the image. The similarity weights are represented as $K = [k_{pq}]_{n^2 \times n^2}$, where $k_{pq}$ is defined as

$$k_{pq} = \exp\left(-\left[\frac{\|p-q\|^2}{2\sigma_s^2} + \frac{|I_p - I_q|^2}{2\sigma_r^2}\right]\right), \quad (1)$$

where $\sigma_s$ and $\sigma_r$ specify the amount of filtering, $p$ and $q$ are the pixel positions, and $I_p$ and $I_q$ are the pixel intensity values [13]. The degree matrix $D$ is defined as

$$D = \text{diag}\left\{\sum_q k(1,q), ..., \sum_q k(n,q)\right\}. \quad (2)$$

The graph Laplacian matrix is derived from $K$ and plays an important role in describing the underlying structure of the graph signal. The graph Laplacian and its normalized version are defined as $L = D - K$ and $L_{\text{normal}} = I - D^{-1/2}KD^{-1/2}$, where $I$ is the identity matrix. For signals defined on graphs, filtering can be done in both the vertex and spectral domains similar to that in conventional signal processing. In the vertex domain, a graph signal $z$ can be filtered using $z_f = D^{-1}Kz$, $z_f = D^{-1/2}KD^{-1/2}z$ or an iterative version of these filters, where $z_f$ is the filtered version of $z$ in the vertex domain. It is to be noted that applying these filters to a signal preserves the DC component of the signal, i.e., low-pass filtering [14]. Spectral graph theory studies the graph properties in terms of eigenvalues and eigenvectors associated with the adjacency or Laplacian matrices of the graph. The set of eigenvectors of $L_{\text{normal}}$ constitute the basis function for the underlying signal defined on graph, and its eigenvalues is known as the corresponding graph frequencies. The eigendecomposition of the real and symmetric normalized Laplacian is given by $L_{\text{normal}} = \sum_i \lambda_i u_i u_i^T$, where $\{\lambda_i\}_{i=1,...,n}$ is the set of eigenvalues and $\{u_i\}$ the set of orthogonal eigenvectors [4].

## 3. DETAIL REMOVAL AND REGION SMOOTHENING

The proposed image abstraction method is realized by applying a progressive filtering process consisting of smoothening and sharpening filters. At the first stage, the original image needs to be converted into a smoothened version consisting of regions with mostly uniform intensity or color. To this end in this work, we propose the use of graph-based filtering methods to reduce contrast in low-contrast regions and to eliminate fine structures such as weak edges and possible noise. The filtering process can be performed both in the vertex and spectral domains. In the vertex domain, an iterative filter is used to remove the weaker edges and preserve the stronger ones, as given by

$$z_f = (D^{-1}K)^l z, \quad (3)$$

where $l$ is the iteration index. In the spectral domain, the signal can be filtered by using a graph filter given by

$$\tilde{z}_f = h(\lambda)\tilde{z}, \quad (4)$$

where $\tilde{z} = \sum_i u_i z$ is the projected signal onto the graph Fourier domain, and $h(\lambda) = \sum_{0 \le i \le j} a_i \lambda_i$ is the filter spectral response representing the Lagrange interpolation polynomial expressed as a function of $\lambda$ with degree $j$, which is an approximated version of $h(\lambda) = (1 + \lambda^2)^{-1}$ as proposed in [15]. The filtered signal $\tilde{z}_f$ in the spectral domain can be regarded as a linear combination of the components of the input signal within a $j$-hop local neighborhood. Since the graph frequencies are within the interval $[0, 2]$ [1], the filter spectral response for a polynomial of degree $j = 2$ can be obtained as

$$h(\lambda) = I - 0.6\lambda + 0.1\lambda^2. \quad (5)$$

Accordingly, the approximated filter spectral response for higher degree polynomials can be derived. It should be noted that the above filter leaves the high-contrast edges mostly unaltered, while it has a strong smoothing effect on more homogeneous regions.

In order to obtain a stylized cartoon/painterly-like image, we perform quantization on the luminance channel of the abstracted image as is given by [4]

$$\hat{z}_f = \Lambda\left(\left\lceil \frac{z_f}{\Lambda} + 1 \right\rceil\right) \quad (6)$$

where $\hat{z}_f$ and $z_f$ are the abstracted image and its quantized version, respectively, $\Lambda$ is the quantization step and $\lceil . \rceil$ denotes the floor operator. The simple quantization operator in (6) is fixed and independent of the underlying image. One can also consider an adaptive image-dependent quantization process to minimize the quantization artifacts.

## 4. EDGE SHARPENING AND STUCTURE ENHANCEMENT

Sharpening is a process used for boosting images with high pass filtering, i.e., amplifying high frequency details in images [4]. Since boosting details in the original image may also result in noise amplification, one needs to first smoothen the image and remove the noise and low-contrast details as much as possible. In order to increase contrast in higher contrast regions, edge detection techniques based on Canny, Laplacian of Gaussian and difference of Gaussian [11], [16] detectors have been widely deployed. The resulting edge maps have been used in the context of a shock filter [17] to highlight edges with large magnitude. In this work, in order to boost the high-contrast regions of the image, we propose the use of iterative graph spectral filtering. The spectral response of the proposed iterative sharpening filter is given by

$$h_{\text{sharpening}}(\lambda) = (I + \gamma\lambda)^l \quad (7)$$

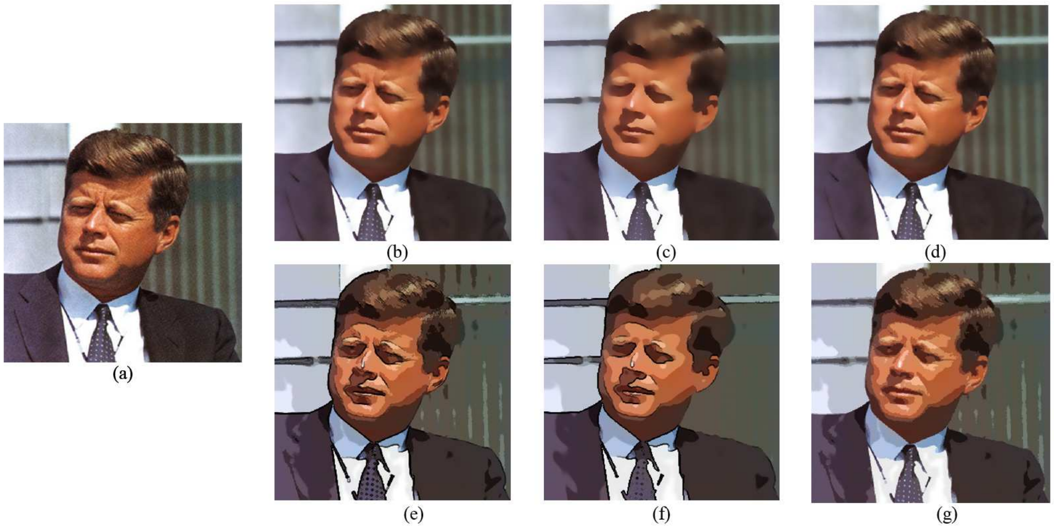

**Fig. 1**: Visual and quality comparisons of various detail removal filters and their influence on final stylized image. (a) Original image, (b) using (3) with $l = 1$, (c) using (3) with $l = 3$, (d) using (4), (e)-(g) stylized versions of (b)-(d), respectively.

For $0 < \gamma < 1$, the above sharpening filter can be regarded as iteratively adding a highpass-filtered version of the luminance channel to the abstracted one. The sharpening filter in (7) can be translated into the vertex domain as $h_{\text{sharpening}}(L_{\text{normal}}) = (I + \gamma L_{\text{normal}})^l$ [4]. One needs to take into consideration the effect of over-sharpening which results in visual degradation and causes unpleasant artifacts in the image. The proposed image stylization method can be summarized as follows

**Step 1:** Convert an RGB color image to Lab color space.

**Step 2:** Construct a regular grid graph with nodes (pixels) connected to their 8-connected neighbors (pixels) and obtain the similarity matrix.

**Step 3:** Perform an iterative detail removal and region smoothening using (3) or (4).

**Step 4:** Perform quantization on luminance channel using (6).

**Step 5:** Perform sharpening using (7) by adding a highpass-filtered version of the luminance to the image.

**Step 6:** Convert the image back to the RGB color space.

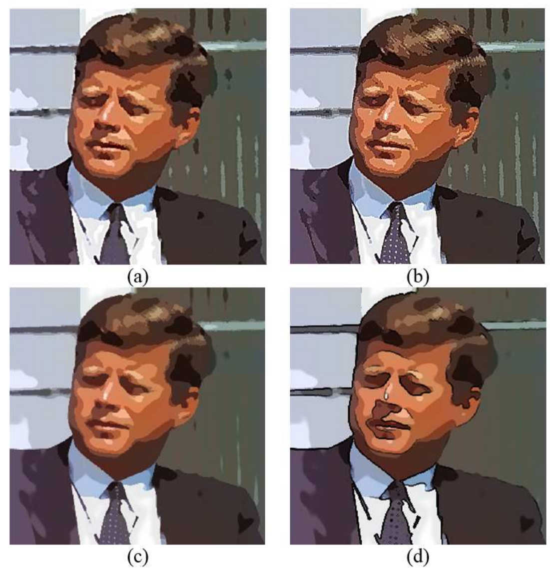

**Fig. 2**: Stylized *JFK* image obtained using (a) Shock filter. (b) Unsharp masking. (c) Difference of Gaussian. (d) Proposed method.

## 5. SIMULATION RESULTS

We conduct experiments on a set of color images to evaluate the performance of the proposed image abstraction and stylization methods. The RGB color images are first converted to the *Lab* color space since this color space is uniform and more similar to the human perception. A grid graph for each color channel is constructed with nodes (pixels) connected to their eight immediate neighbors. In our simulations, the quantization step $\Lambda$ is considered to be constant and set to $15$. We first consider the image abstraction problem and use the filters in (3) and (4) to obtain the abstracted images. Fig. 1 shows one of the test images, *JFK* image with inherent noise, its abstracted versions obtained using the proposed iterative vertex and spectral domain graph filters and their corresponding stylized images. It is seen from this figure that graph filters smoothen the image by removing fine details while preserve the high-contrast edges. It is also seen that increasing the iteration index $l$ results in smoother abstraction and a stylized image with better quality.

We then compare the performance of the proposed image stylization method using graph-based filtering to that of other existing methods, namely, unsharp masking, shock filter and difference of Gaussian-based image stylization. For the case of difference of Gaussian edge detection, we use our graph-


**Fig. 3**: Stylized *Margaret* image obtained using (a) Shock filter. (b) Unsharp masking. (c) Difference of Gaussian. (d) Proposed method.

based detail removal method for image abstraction. Figs. 2 and 3 illustrate the stylized *JFK* and *Margaret* images, respectively, obtained using the proposed method as well as those obtained from the other approaches. The original *Margaret* image is first contaminated by an additive Gaussian noise with noise standard deviation $\sigma_n = 0.1$. It is seen from these figures that the proposed method has a better performance than other approaches since it provides cartoon-like images with no horizontal or vertical artifacts and creates smooth and coherent transitions along line and curved boundaries.

## 6. CONCLUSION

In this paper, we have presented an efficient method for image abstraction and stylization, which has produced encouraging results that provide perceptual feeling like cartooning. The proposed method has been established by leveraging the recent advances in the field of graph signal processing. The proposed image abstraction method is composed of iterative filtering for detail removal and region smoothening followed by luminance channel quantization and edge sharpening to generate cartoon-like effects in the output image. Experiments have been carried out using real images. The results have shown that the proposed method can produce multi-level abstracted images while retaining much of their perceptually important information. The resulting stylized images are visually more pleasant than those yielded by other methods.

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