

WAVELET BASED NONLINEAR SEPARATION OF IMAGES

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Partially funded by FCT (Portugal)





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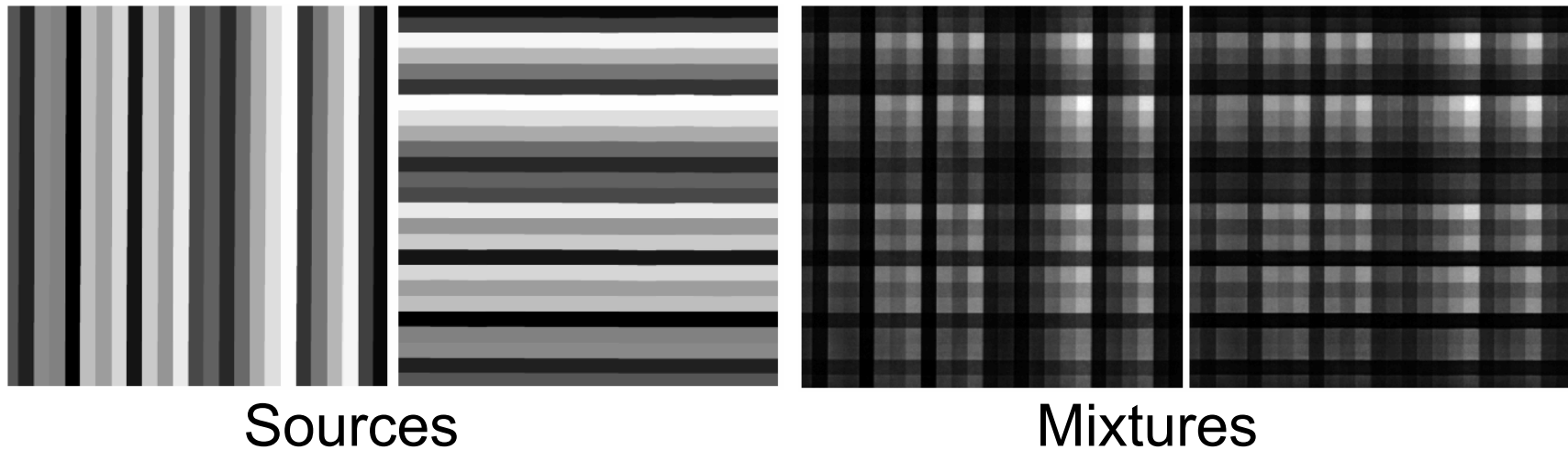
Lisbon, Portugal



Outline

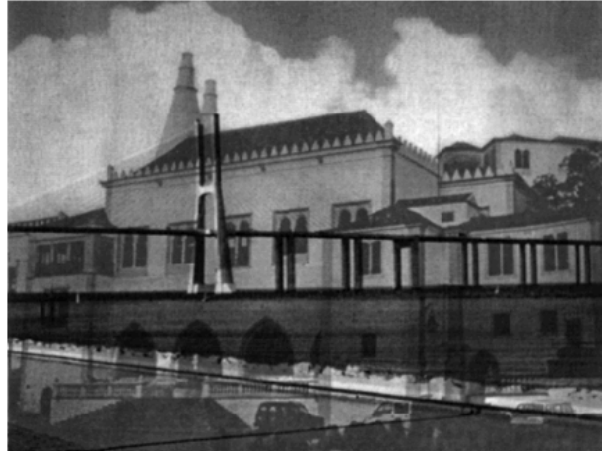
- Nonlinear mixture of images
- Separation method
- Results
- Conclusions

Mixing problem



- Mixture of the front- and back-page images of a document when acquired with a scanner
- The mixture is nonlinear and noisy
- Five different pairs of mixtures were studied.

Mixing problem



Mixing problem

Separation of nonlinear image mixture

When acquiring an image of a printed document, the image printed on the opposite page often shows through. Co-located transparency of the paper, however, is not always the case. This is due to the fact that the paper is not perfectly uniform.

To analyze the mixture, a scatter plot of the intensities of corresponding pairs of pixels from the two pages of a printed document was constructed. The scatter plot of the original images, shown in the top figure, shows a dense cloud of points, and had only a relatively small number of discrete intensity levels in each image. The fact that the scatter plot of Fig. 1 is very different from a parallelogram shows that the mixture was severely nonlinear. The fact that the scatter plot becomes a parallelogram indicates that, for these images, the mixture is close to linear. Finally, due to noise in the process, the process leading from the sources to the observations involved printing the images on both sides of a sheet of skin paper, at 1200 dpi, with a black and white laser printer (with the printer's resolution of 600 dpi), and then scanning both sides of the printed sheet at 300 dpi. The noise is due, at least, to the printing process (including the halftone) in the scanning process and in the non-uniformity of the skin paper, especially in its transparency.

The scatter plot of separation is obtained from the original images for an obtained by scanning both faces of the printed document, the images that had been printed in each of its faces, with as little interference from the other image as possible.

In this example, an image printing mixture that is not a linear mixture, printed on one page, the special characteristics of printed text and graphics, normally known as "black and white" through, due to the above mentioned noise, they will appear in the scanned images, as two clusters of

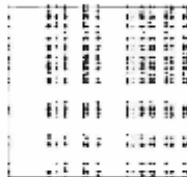


Figure 1.1

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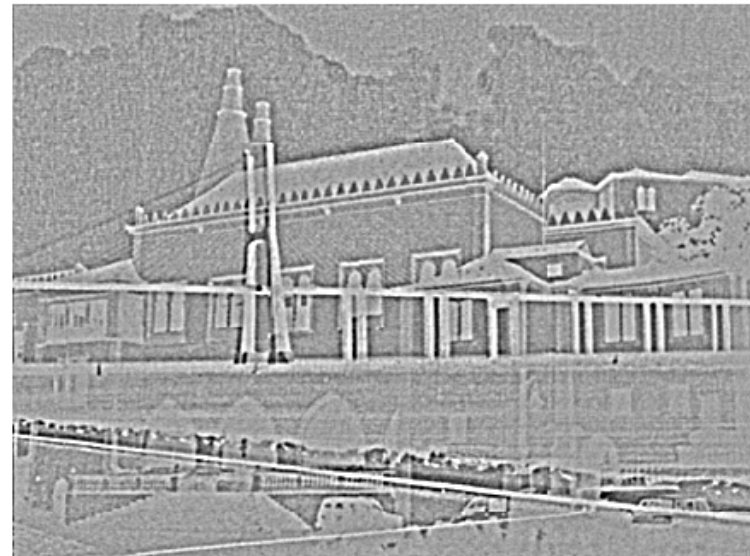
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Figure 1.1

Separation method - motivation

- Image edges are sparse
- Almost no superposition between edges of two different images
- In each mixture one of the sources (and its edges) is more intense than the other



High frequencies of a pair of mixture images

Separation method - motivation

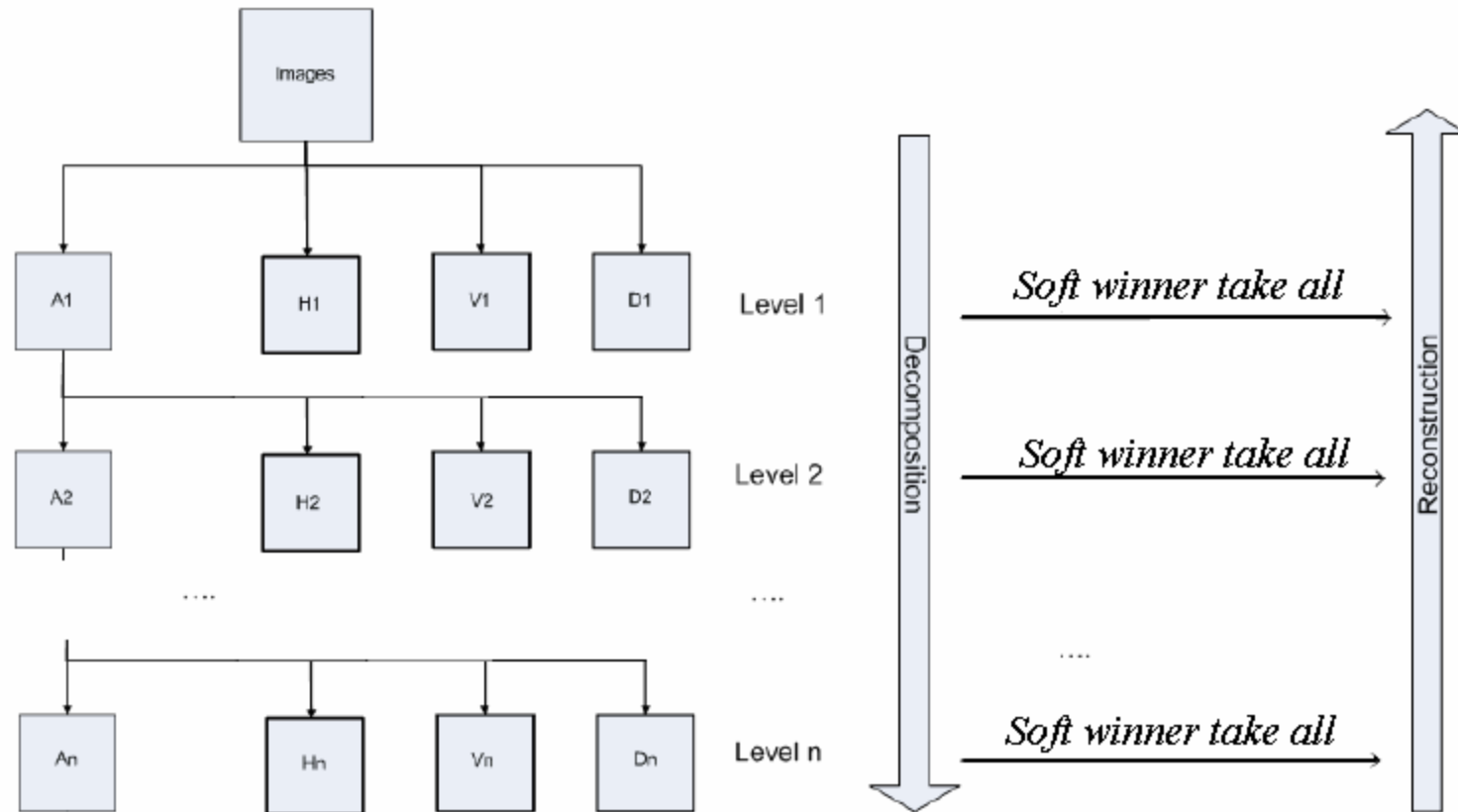
High frequencies after a *soft winner take all* operation



Edges are almost completely separated

Separation method

- *Soft winner take all* is applied to high frequency wavelet coefficients





Separation method

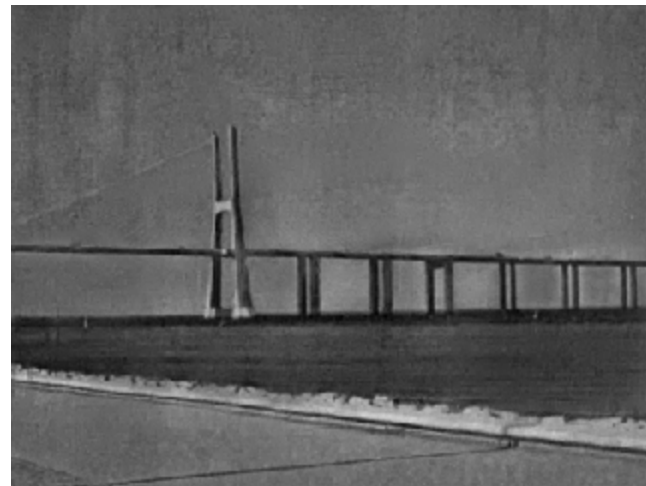
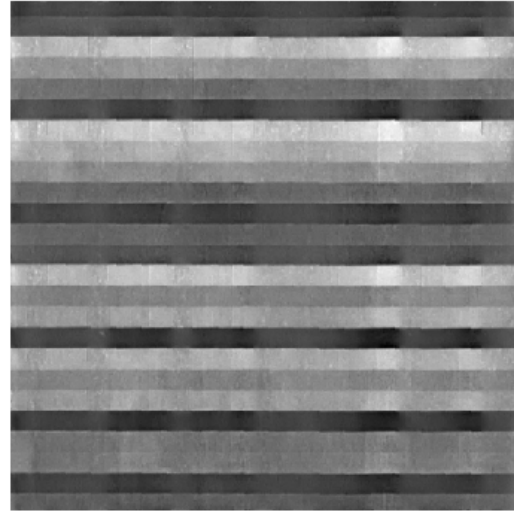
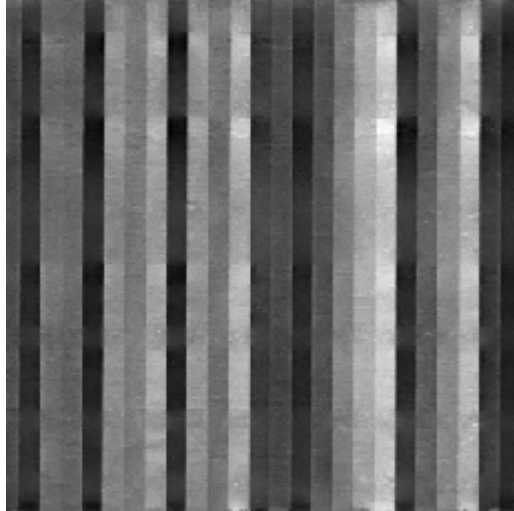
- Two different wavelets were considered
 - Complex wavelet transform (faster processing)
 - Almost shift-invariant
 - Relatively large support wavelets
 - Stationary wavelet transform (better results)
 - Shift-invariant
 - Small support wavelets (“Haar”)
- A linear pre-processing “decorrelates” the data



Experiments

- Best results (from visual evaluation)
 - Shift-invariant “Haar” wavelets
 - Linear preprocessing of the mixtures (decorrelation)
 - 7 wavelet decomposition levels (image size 400x400)
 - 8 wavelet decomposition levels (image size 800x800)

Results (1)



Results (2)

Separation of nonlinear image mixtures

When acquiring an image of a printed document, the image pointed on the opposite page often shows through, due to partial transparency of the paper. Here we are dealing with quite a serious case of this effect, because we're using glass paper which is quite transparent.

The mixture that is obtained is rather nonlinear, as can be observed from the top figure on the right, which shows a scatter plot of the intensities of corresponding pairs of points from the two pages of a printed document. The scatter plot of the original images, shown in the bottom figure, filled a square, and had only a relatively small number of discrete intensity levels for each image. The fact that the shape of the scatter plot of Fig. 1 is very different from a parallelogram shows that the mixture was strongly nonlinear. The fact that this scatter plot becomes quite narrow in the upper-right corner (which corresponds to the higher intensities in both images) indicates that, for those situations, the mixture is close to singular. Finally, the fact that the discrete levels of Fig. 2 became largely smeared in Fig. 1 is due to noise in the process. The process leading from the sources in the observations involved printing the images on both sides of a sheet of coated zinc paper, at 1200 dpi, with a black and white laser printer (with the inherent limitation of gray levels), and then scanning both sides of the printed sheet at 100 dpi. The noise is due, at least, to the printing process (including the halftoning), to the scanning process and to the non-uniformity in the zinc skin paper, especially in its transparency.

The purpose of separation is to recover, from the mixed images that are obtained by scanning both faces of the printed document, the images that had been printed in each of its faces, with as little interference from the other image as possible.

In this example we are seeking mixtures that involve natural images, printed text and graphs. The special characteristic of printed text and graphs is that they normally involve just two intensity levels (black and white) although, due to the above mentioned noise, there will appear, in the scanned images, as two clusters of intensity levels.

The separation of mixtures of two-level images, such as printed text, may be much easier than the separation of grayscale images. In fact, at least in the case of mixtures that are not too strong, a simple thresholding procedure may yield the desired results. Such a procedure can be easily performed by hand with image processing programs, and should not be hard to automate. In such a case the use of more general blind source separation methods might be an overkill, both because it would involve a much larger amount of processing and because it might actually yield worse results. This is an extreme case in which prior knowledge about the sources can strongly simplify the separation process.

In the case of grayscale mixtures, the use of a regression method based on a good model of the physical mixing process should yield much better results than the use of a generic nonlinear separation method. A physical model could have a small number of parameters to be estimated, and would thus allow a much more precise estimation. Furthermore, it might avoid the inherent ill-posedness of nonlinear blind separation, which is currently addressed through regularization. The parameters of such a model could be estimated by an independent component analysis technique.

Another issue of interest is the definition of separation criteria that are more suited for images in the printed documents than statistical independence. In fact, images on the two sides of a printed document can easily happen not to be independent from one another. For example, images of landscapes tend to be lighter on the top than on the bottom, including a correlation between intensities of both. Also, in printed text with regularly spaced lines, the lines from both sides of the paper may happen to fall on top of each other, or the lines from one side may fall on the intervals of the lines from the other side, also inducing a significant




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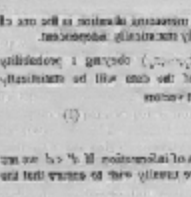
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Conclusions

- Method for separating a real-life nonlinear mixture of images
- Non-iterative and fast
- Exploits the sparsity of the image edges
- Yields good perceptual separation quality
- We plan to evaluate the separation quality of the images by MOS (Mean Opinion Score) tests