

SEPARATING NONLINEAR IMAGE MIXTURES USING A PHYSICAL MODEL TRAINED WITH ICA

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Partially funded by FCT (Portugal)





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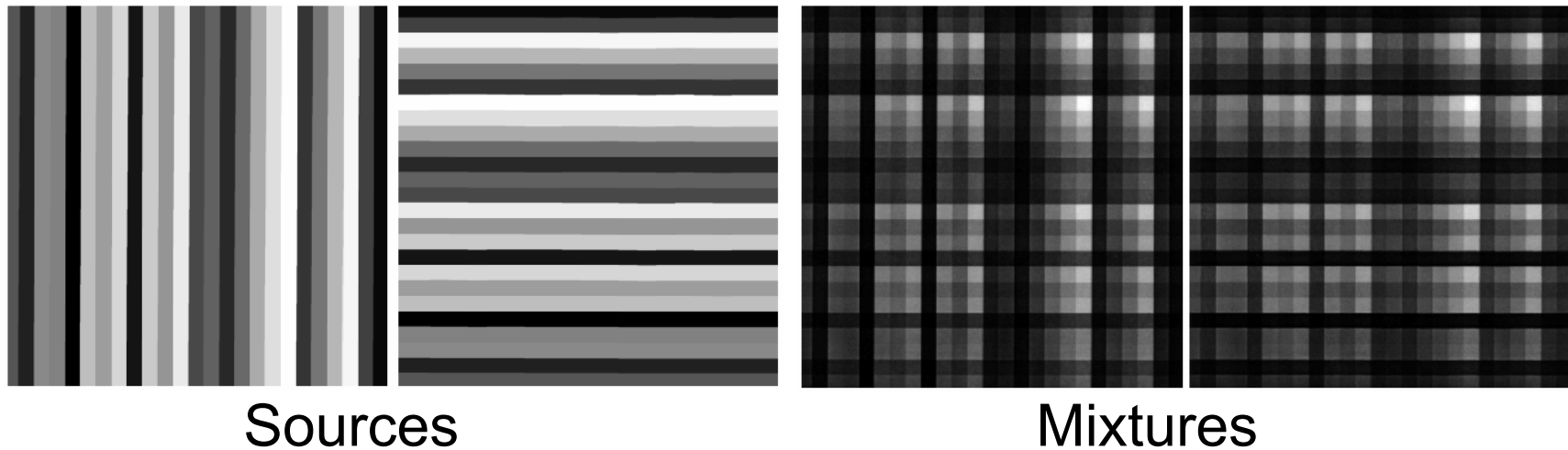
Lisbon, Portugal



Outline

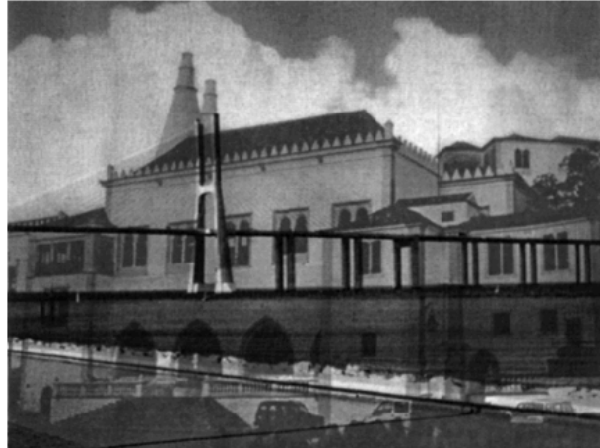
- Nonlinear mixture of images
- MISEP ICA method (brief review)
- Physical model of the mixing process
- Inverse model for separation
- Experiments and results
- Conclusions

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

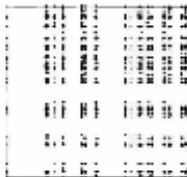
Separation of nonlinear image mixture

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 working at 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 in 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 two pages, the special characteristic of printed text and graphics is normally linearly mixed, mainly levels black and white, although, due to the above mentioned noise, there will appear in the scanned images, a few clusters of



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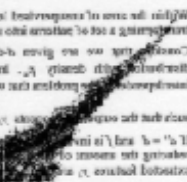
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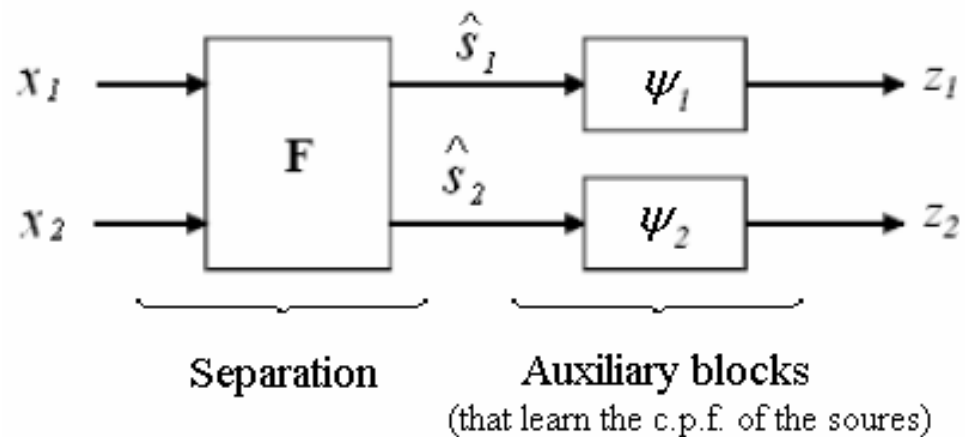
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MISEP method

- Performs nonlinear ICA by minimizing mutual information



- Generalizes *Infomax* in two directions
 - Allows nonlinear functions in the separation block F
 - Adaptive output nonlinearities

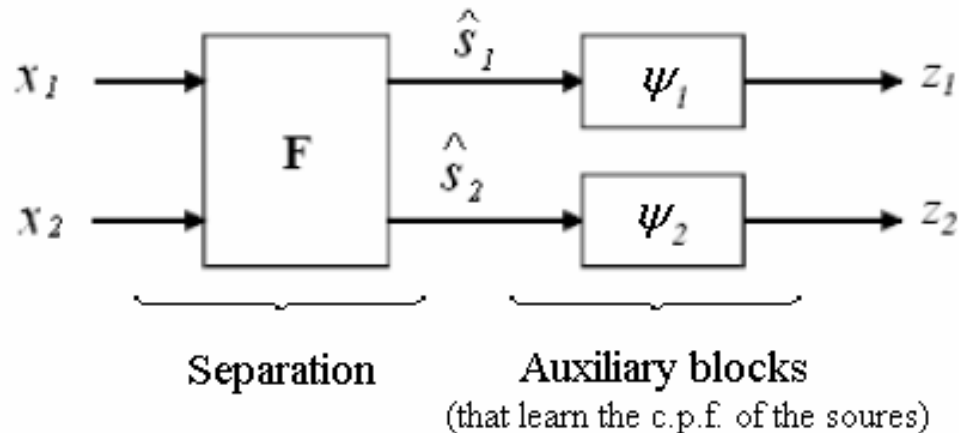
Mixing model

- Based on the *halftoning* process of the printers
 - The printer produces small black dots
 - The gray level is given by the fraction of area covered by the dots
 - We model the dots by a random binary variable
 - With suitable assumptions, a bilinear mixing model can be derived

$$\begin{cases} x_1 = \alpha s_1 + \beta s_2 + \gamma s_1 s_2 + \delta \\ x_2 = \alpha s_2 + \beta s_1 + \gamma s_2 s_1 + \delta \end{cases}$$

s_i - sources x_i - mixtures

Inverse (separation) model



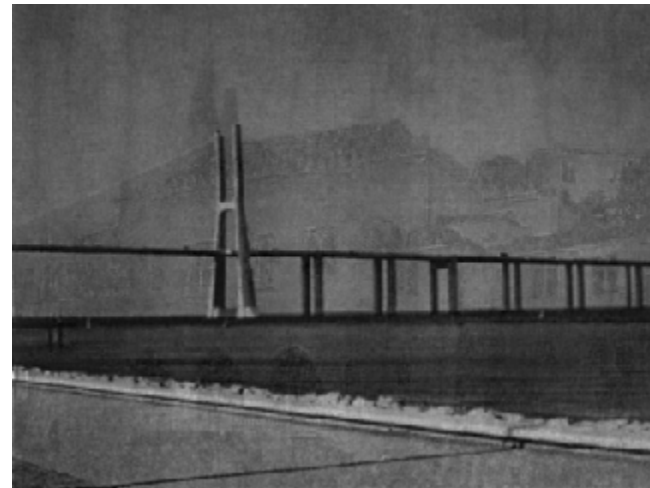
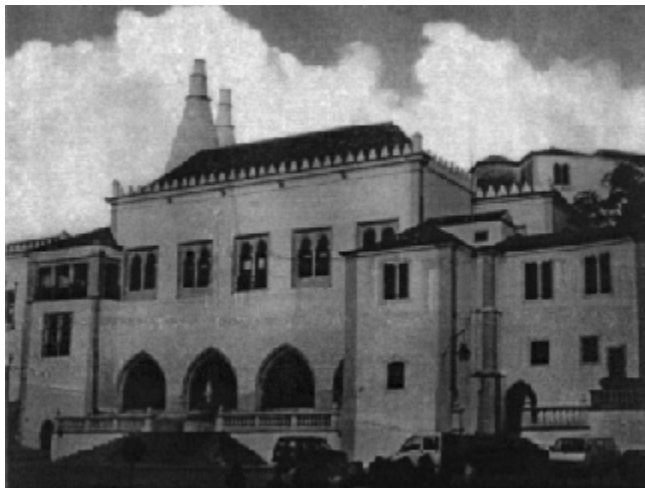
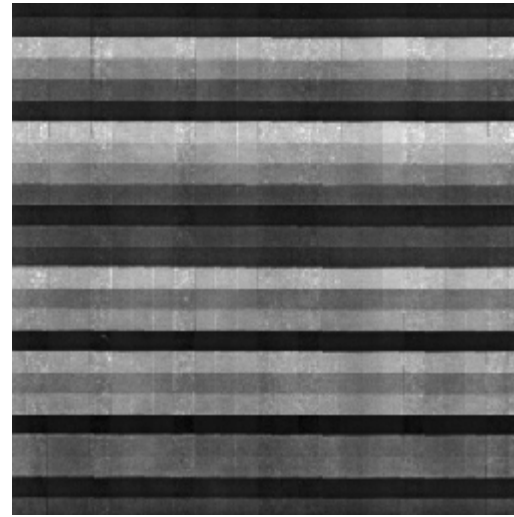
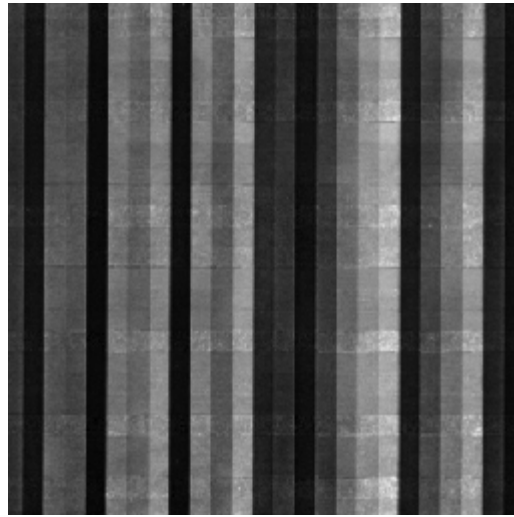
- F implements the inverse of the physical mixture model
- This inverse can be found algebraically
- Equations not shown here due to complexity
- This inverse has the same four parameters as the physical mixture model
- These four parameters are what needs to be estimated by the MISEP method



Experiments

- The **F** Block was initialized near the identity function
- Auxiliary blocks were MLPs with 10 hidden units each
- MISEP was applied to each pair of mixtures during 1000 epochs.
 - A separation model was trained for each pair of mixtures
 - Training set: 1000 pairs of pixels, randomly selected

Results (1)



Results (2)

Separation of mirrored image mixtures

When acquiring an image of a printed document the image printed on the opposite page often shows through, due to partial transparency of the paper. Since we are dealing with pairs a strong case of that effect, because we are using ordinary office paper which is quite transparent.

The images that are obtained a 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. These images, are not only a relatively small number of discrete intensity levels for each image, but also the slope of the scatter plot of log₂ is very different from a randomization noise that the document was strongly processed, the fact that the scatter plot became quite narrow in the upper-right corner (which corresponds to the higher intensities in both images) indicates that, for those intensities, the mixture is close to negligible. Finally, the fact that the discrete levels of Fig. 2 became largely blurred in Fig. 1 is due to noise in the process. The process leading from the mixture to the observations involved printing the images, at both sides of a sheet of an 8 1/2 x 11 paper, at 1200 dpi, with a black and white laser printer (with the intensity modulation 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 fluctuations in the scanning process) and to the non-uniformity in the original 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, two images that had been printed in each of its faces, with as little interference from the other image as possible.

In the mixture we are dealing with here, this involves mixed images, printed and not scanned. The special characteristics of printed lines and graphics (for example, normally regular line widths and white spaces) although, due to the above mentioned noise, these will appear in the centered images as thin clusters of intensity levels.

The extension of mixtures of two-level images, such as printed text, may be much more than the separation of gray-level 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 most image processing programs, and should not be hard to automate. In such a case the use of more general statistical separation methods might be an overkill. Both because it would involve a much larger amount of computing and because it might actually yield worse results. This is an extreme case in which good knowledge about the sources can obviously simplify the separation process.

In the case of gray-level mixtures, the use of a separation 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 often a much more precise estimation. Furthermore, it might model the inherent dependencies of nonlinear color separation, which is currently addressed through regularization. The parameters of such a model could be estimated by an independent component analysis technique.

Another area of interest is the definition of separation criteria that are more suited for images or for printed documents than statistical independence. In fact, images and/or text from the opposite pages of a printed document can easily happen not to be independent from one other. For example, images of landscapes tend to be brighter on the top than on the bottom, assuming a correlation between illumination of both sides 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, including a statistical correlation between intensities from both sides of the document, it would be interesting to see whether based on a notion of image complexity, but those may not be easy to define, and may be even harder to use as criteria for optimizing a source separation process.



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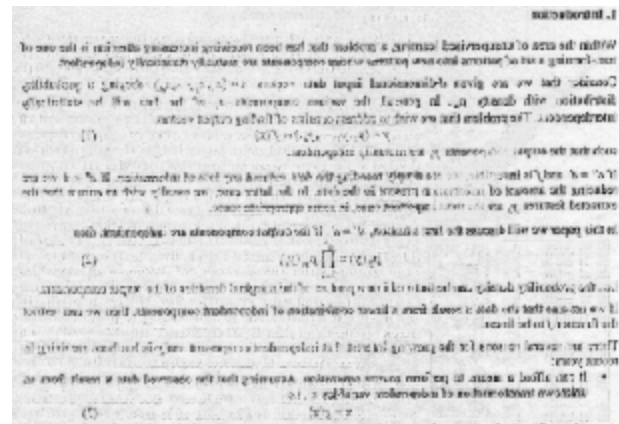
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Objective quality measures

- Three quality measures were computed
 - Q1 – SNR between extracted and original source
 - Q2 – Same as Q1, but compensated for possible nonlinear intensity distortion
 - Q3 – Mutual information between extracted and original source



Results

Quality measure	Physical model	MISEP MLP	Nonl. DSS
Q_1 (dB)	12.4	11.8	11.9
Q_2 (dB)	13.6	13.0	13.3
Q_3 (bit)	2.12	1.98	2.07

MISEP MLP – MISEP using an MLP in the separation block (L.Almeida JMLR 2005)

Nonl. DSS – Nonlinear Denoising Source Separation (M.S.C Almeida ICA 2006)



Conclusions

- A physical model for the mixing process of scanned images was presented
- The inverse model was trained using MISEP (ICA)
- The separation quality is better than those obtained with previous methods for the same data (according to objective quality measures)
- The physical model fits the mixture process well
- MISEP is appropriate for estimating the model parameters