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Image and signal processing in medicine and biosciences

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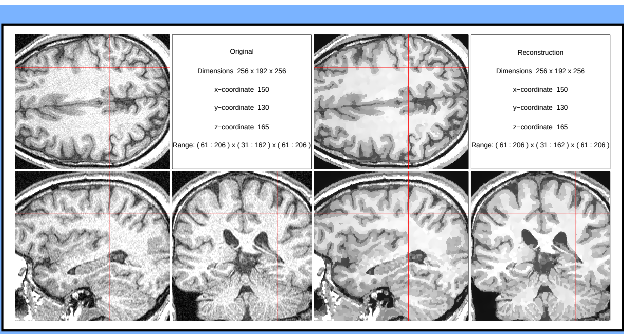
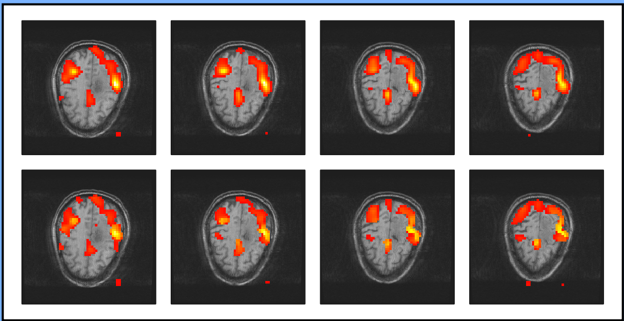
Medical imaging

Medical imaging includes a variety of techniques, like X-Ray, CT, and MRT. A high noise level and very low signal-to-noise ratio together with heteroskedastic tissue dependent variance is often a serious problem. Objects and signals of interest are often very weak and can hardly be detected. Methods and algorithms to handle this kind of data should be able to reduce noise while preserving important structure like edges and homogeneous regions. Adaptive Weights Smoothing (AWS) removes the noise without loosing the structural information. This leads to substantial improvements in the analysis of various types of medical images.



Reconstruction of a **MR image**. Left: original image, Right: result of structural adaptive smooting



Signal detection in fMRI analysis for non-adaptive (upper row) and adaptive smoothing (lower row)

AWS

- **Initialization:** global MLE

$$\hat\theta_i^{(0)} := \frac{1}{n}\sum_j Y_j, \quad w_{ij}^{(0)} = 1$$

- **Iteration:** define adaptive weights

$$w_{ij}^{(k)} = K_l(l_{ij}^{(k)})K_s(s_{ij}^{(k)})$$

where K_l, K_s are kernel functions,

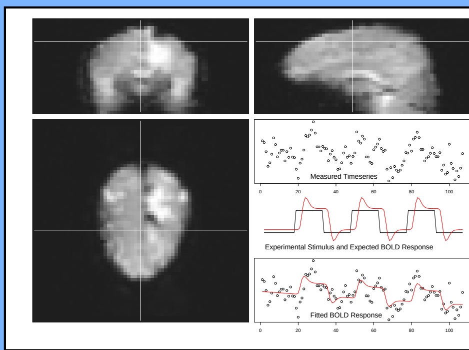
$$l_{ij}^{(k)} = |X_i - X_j|/h^{(k)}$$

is a location penalty and

$$s_{ij}^{(k)} = \frac{1}{\lambda}\sum_l w_{il}\,\mathcal{K}\left(\hat\theta_i^{(k-1)}, \hat\theta_j^{(k-1)}\right)$$

a statistical penalty. Generate new estimates

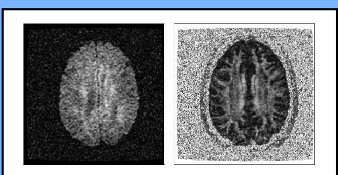
$$\hat\theta_i^{(k)} := \sum_j w_{ij}Y_j \Big/ \sum_j w_{ij}.$$



Properties of fMRI data

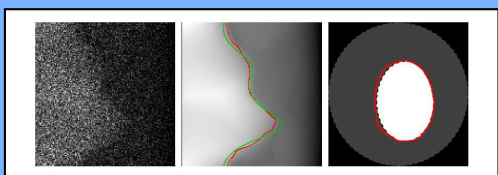
fMRI

Data from functional magnetic resonance imaging (fMRI) consists of time series of brain images which are characterized by a high noise level and a low signal-to-noise ratio. In order to reduce the noise, improve signal detection and to solve the multiple test problem fMRI data is spatially smoothed. However, the common application of a Gaussian filter does this at the cost of loss of information on spatial extend and shape of the activation areas. Here we suggest to use structural adaptive smoothing procedures instead. This significantly improves the information on the spatial extend and shape of the activation regions with similar power of signal detection.



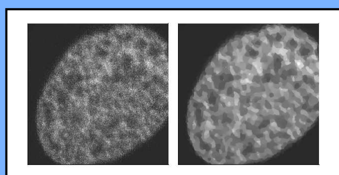
DTI

Within Diffusion Tensor Imaging (DTI) one measures the diffusion of water in the brain (or other tissues), which can be highly anisotropic. This reveals information on the structure. An appropriate modelling of DTI data requires to develop adaptive smoothing procedure that identify and use anisotropy information in the data.



PET

The observed data follow a Poisson distribution whose intensity is the Radon transform of the objective tissue. The theoretical results lead to the following procedure: apply the AWS procedure for Poisson data on the observed image and detect the discontinuities of the first derivative of the estimated intensity. The inverse Radon transform of the discontinuities describes the tissue borders.



Microbiological images

Microbiological images are often characterized by a high noise level and a bad signal to noise ratio. The distribution of gray values strongly depends on the imaging technique. The Figure shows a slice of a 3D image of a cell nucleus obtained by confocal microscopy and its reconstruction by a local constant AWS procedure.