MS lesion segmentation in MR image: a multithresholding approach

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Multiple Sclerosis (MS) is an autoimmune, chronic and disabling disease of the human central nervous system, histologically characterized by multifocal areas of inflammatory demyelination within white matter (WM) and grey matter (GM).
The current MS diagnostic criteria include cerebral and spinal Magnetic Resonance Imaging (MRI) to demonstrate the dissemination in space and time of inflammatory lesions.

In order to obtain useful information about the status of the illness such as:

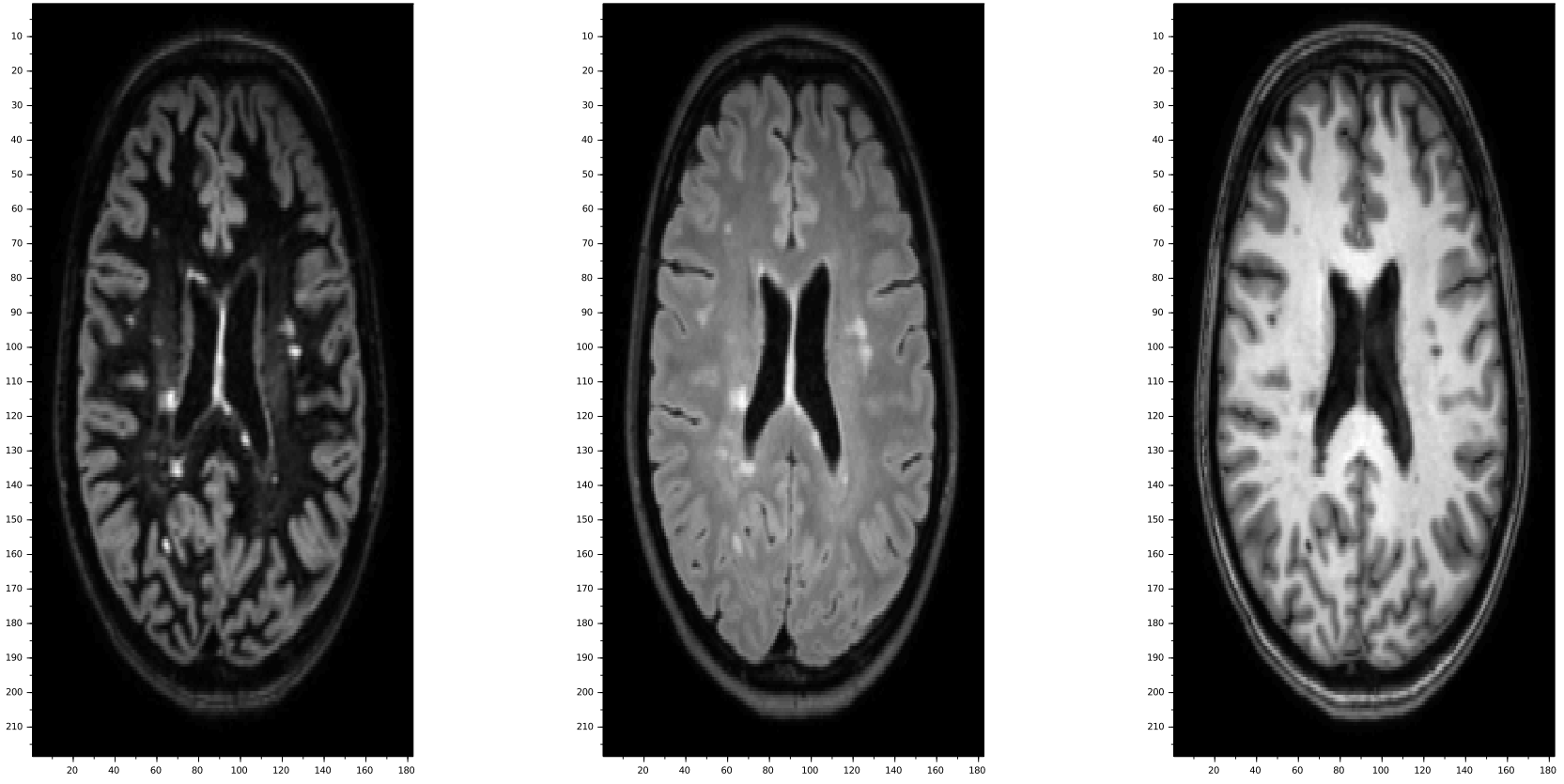
- (mean) cortical thickness,
- WM volume, GM volume,
- WM lesion volume, GM lesion volume

a segmentation of the brain 3D MRI images is needed.

Segmentation of an image

$$f : \Omega \subset \mathbb{R}^3 \to \mathbb{R}$$

is the partitioning of $\Omega = \cup_{i=1}^{n} \Omega_i$ such that f is almost constant on each segment Ω_i.
Manual segmentation is difficult and time-consuming, hence an efficient automatic method is needed.



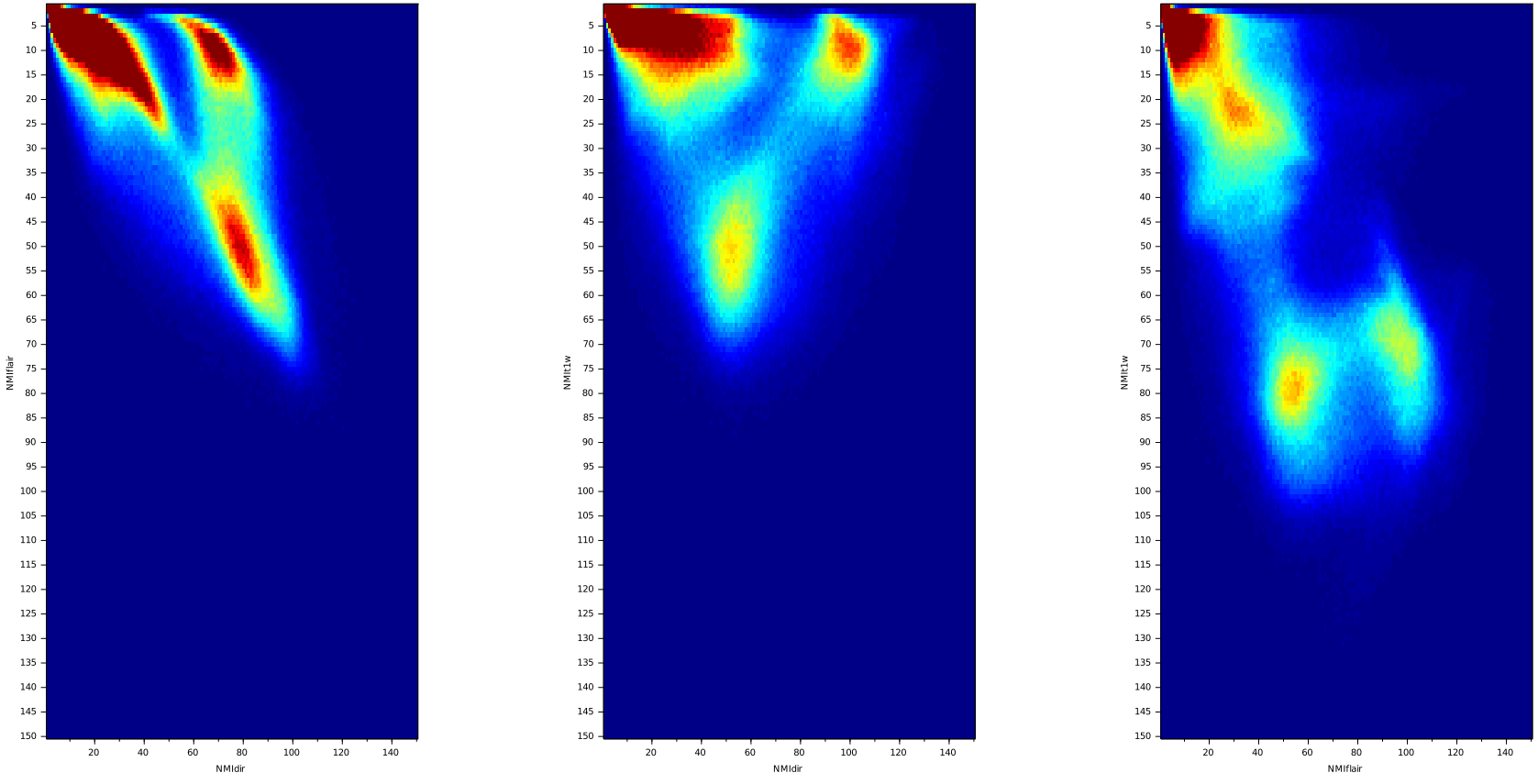
Aligned MRI images of DIR, FLAIR, T1w sequences of the same brain at the same slice.

The histogram of a signal $s = (s_1, \ldots, s_n)$, $s_i \in [0, N-1]$ is defined as

$$h_i = |\{s_k = i+1\}_{k=1,\ldots,n}|, \quad i = 1, \ldots, N$$

The joint histogram of two aligned signals $s = (s_1, \ldots, s_n)$, $t = (t_1, \ldots, t_n)$, $s_i, t_i \in [0, N-1]$ is the matrix

$$H_{i,j} = |\{s_k = i+1, t_K = j+1\}_{k=1,\ldots,n}|, \quad i, j = 1, \ldots, N$$



Joint histogram of the three images computed two-by-two.

A peak of a map, for instance

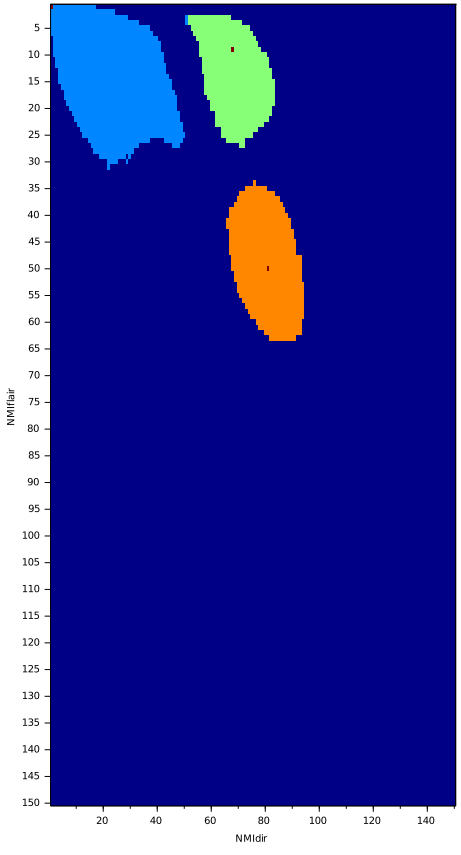
$$f : \Omega \subset \mathbb{R}^2 \to \mathbb{R}$$

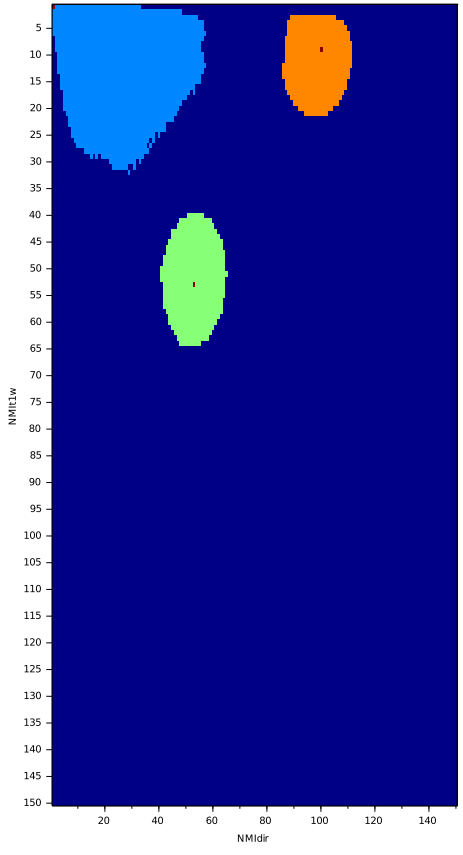
is simply a point of local maximum $\bar{x}$.
Hence a point such that $\nabla f(\bar{x}) = 0$ and $H_f(\bar{x})$ is positive definite.

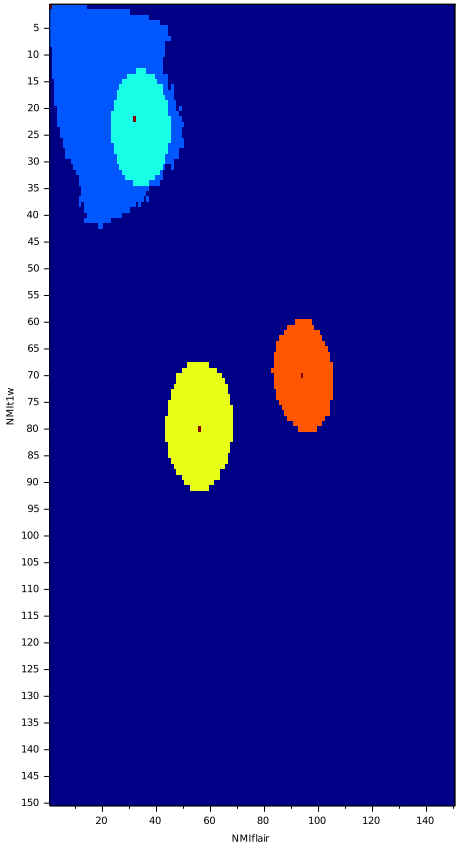
To assign an area of influence to each of the peaks, we think the joint histogram as a mass map of some bodies using the well-known formula

$$F = \frac{m_1 m_2}{d^2} = \frac{m(x) - m(p)}{\|x - p\|_2^2}$$

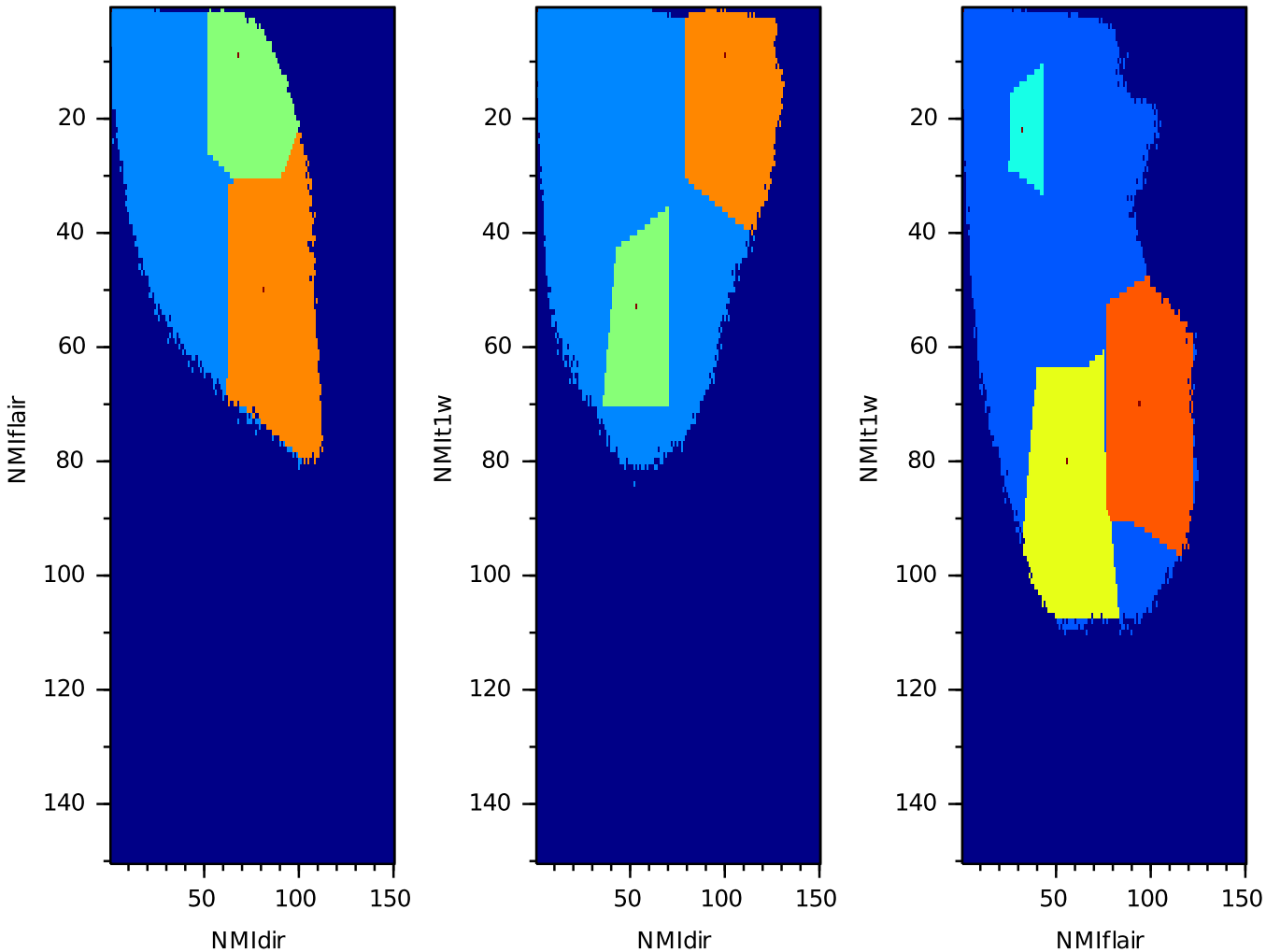
where p is the peak and x a point of the histogram. A point x belongs to the orbit of p if the force F is greater than the force applied by all the other peaks p'.



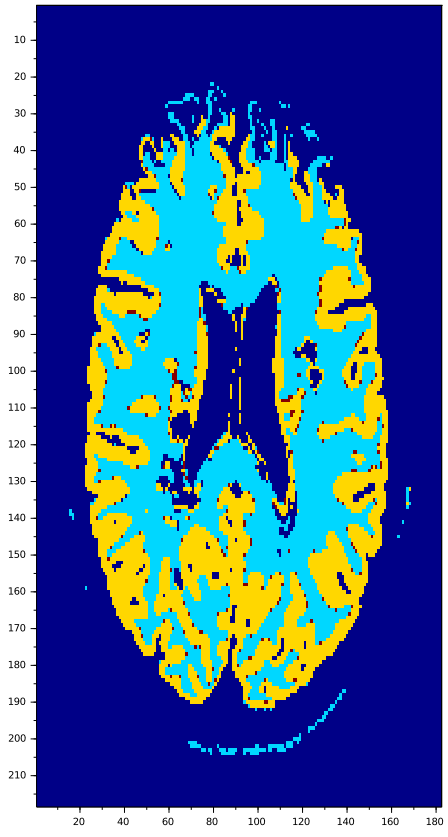
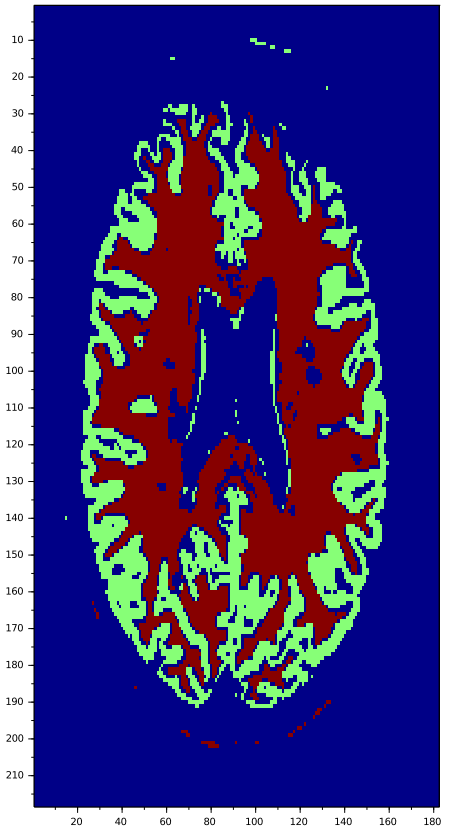
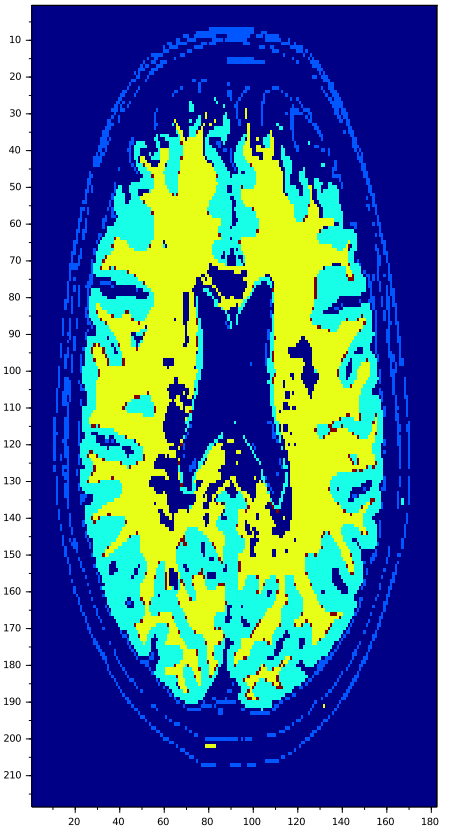




Gravity maps over the joint histogram.



Gravity maps of the same histogram, using the Chebyshev distance.

Maps obtained by threshold coupled images as indicated in the gravity maps.

Let $I \in \{0,1\}^{NxxN}$ be a binary (n-dimensional) image. I can be represented as the set of its non-zero indexes,

$$A = \{p | I(p) = 1\} \subset \mathbb{Z}^n.$$

For instance the 2D cross is
$H = \{(1,0),(0,1),(0,0),(-1,0),(0,-1)\}$.

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On such sets we can define a number of operations:

- union and intersection as usual
- inversion: $\bar{A} = \{p \notin A\}$
- shift by $v \in \mathbb{Z}^n$: $A_v = \{a + v | i \in A\}$
- reflection: $H^* = \{-h | h \in H\}$

Given $H \in \mathbb{Z}^n$ a structuring element and I a binary image we can define:

Dilation by H

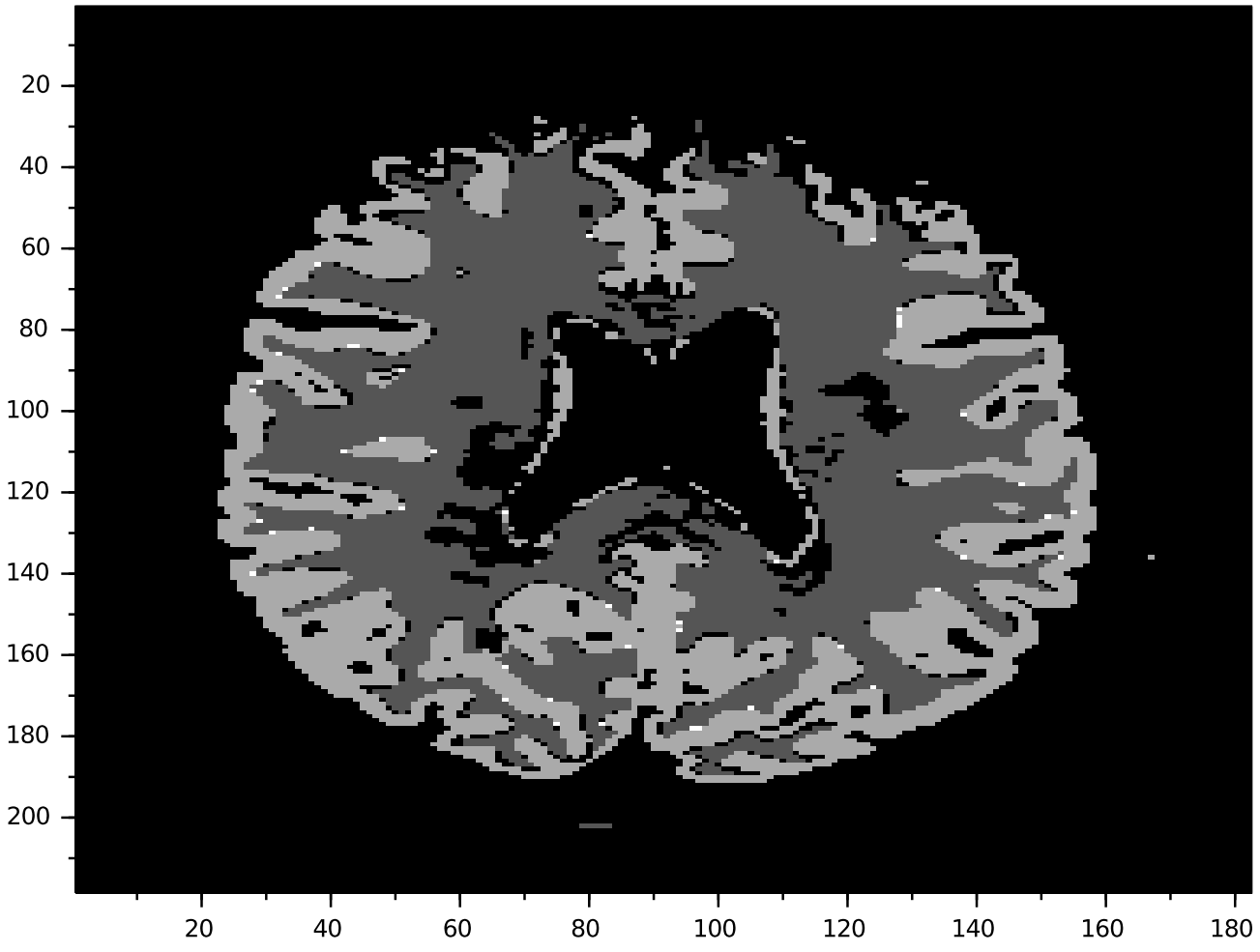
$$A \oplus H = \{a + h | i \in A, h \in H\} = \bigcup_{h \in H} A_h$$

Erosion by H

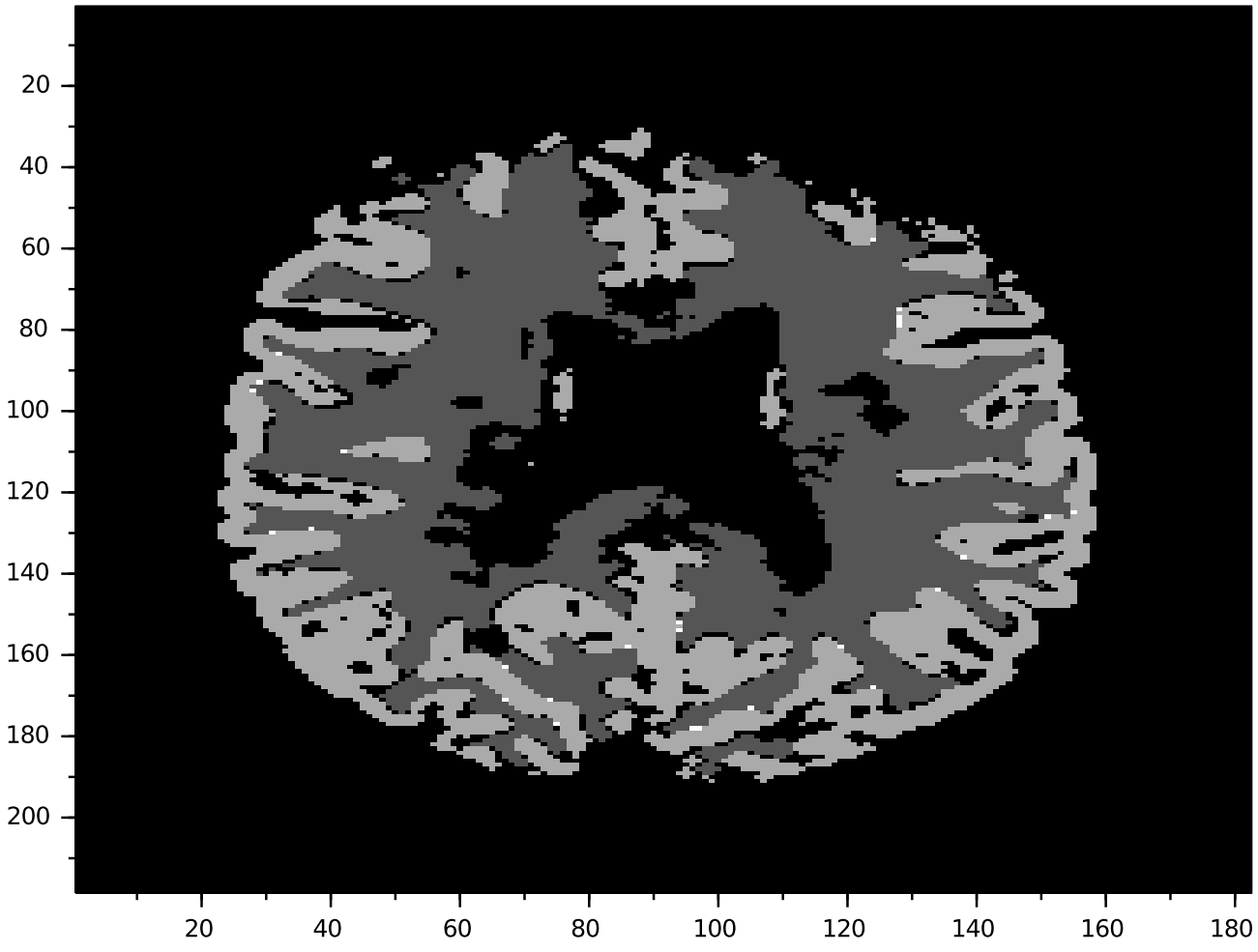
$$A \ominus H = \{a - h | i \in A, h \in H\} = \bigcup_{h \in H} A_{-h}$$

Erosion is not the inverse of dilation but

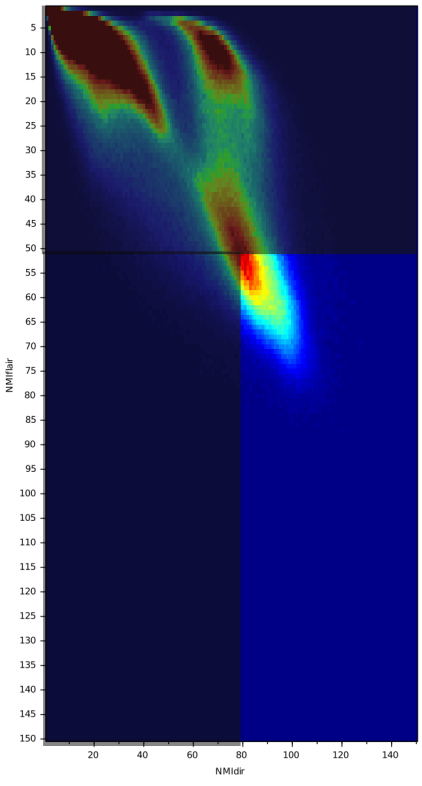
$$A \oplus H = \overline{\bar{A} \ominus H^*}$$

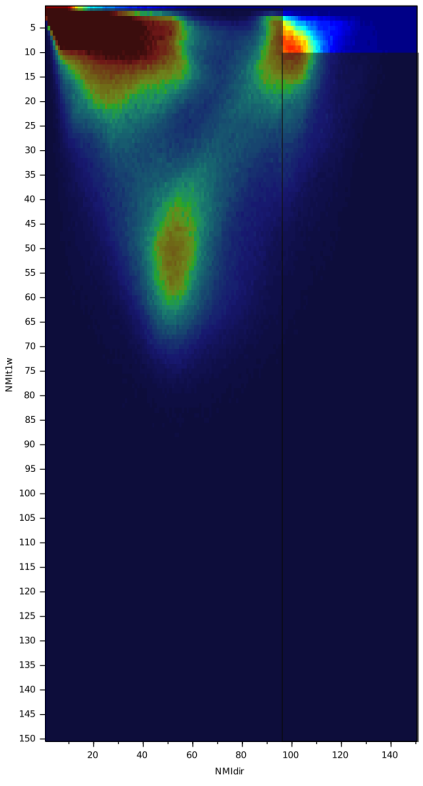


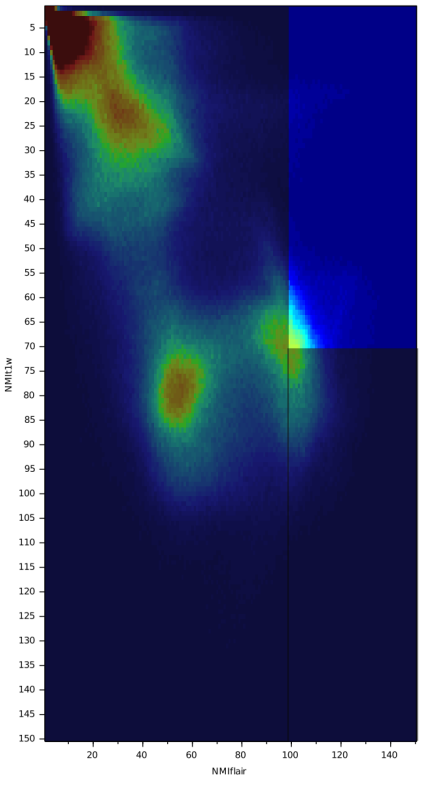
Segmentation of GM and WM before...



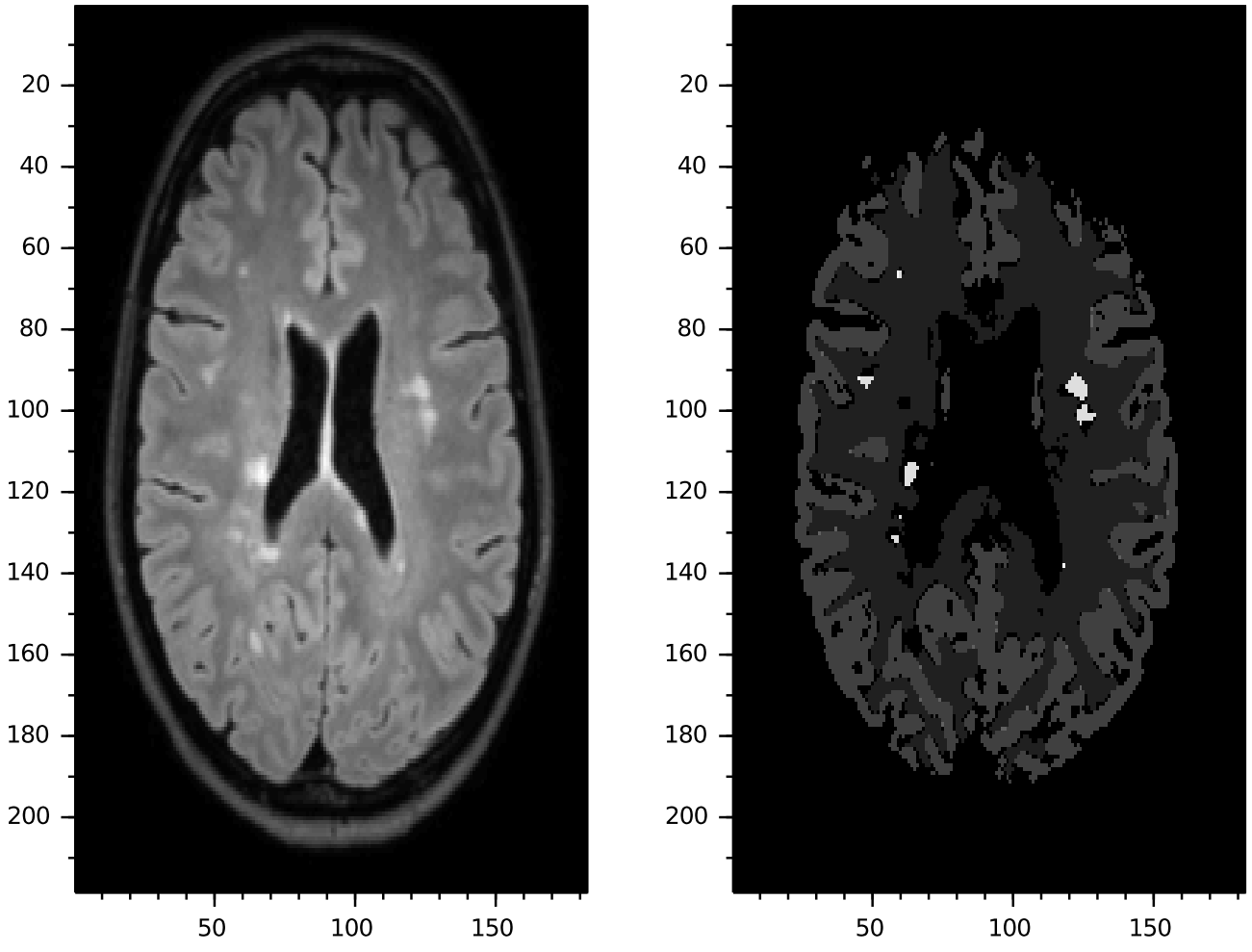
...and after one erode-dilate cycle using the 3d cross.







For finding the lesions, we extract a part of the joint histogram and look for peaks in this area.



Lesion map found by the algorithm.

What we have done:

- fast algorithm for WM lesion mapping (1 min of total running time)
- preliminary tests on 10 patients

To be done/work in progress:

- validation of the algorithm by comparison over manually drawn maps
- apply a similar algorithm for GM lesions (more challenging)
- relaxation of the algorithm in order to find local hyper/hypo-intensities

The softare package descibed in this presentation, Automatic Lesion Segmentation, is available in Scilab File Excange at the Image Processing section
https://fileexchange.scilab.org/toolboxes/324000
As input three co-registered 3D DIR, FLAIR and T1w images are needed in Nifti (.nii/.nii.gz) or Analyze (.hdr, .img) format. As output the user can save the desired map (GM, WM or lesion map) in Analyze format.

Thank you!

 F Kurugollua, B Sankurc, A.E Harmancidl, *Color image segmentation using histogram multithresholding and fusion*, Image and Vision Computing, 2001

 Z Zeng, R Zwiggelaar, *Joint Histogram Modelling for Segmentation Multiple Sclerosis Lesions*, Springer Berlin Heidelberg, 2011

 W Burger, MJ Burge, *Principles of Digital Image Processing: Fundamental Techniques*, Undergraduate Topics in Computer Science, 2009