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White and Grey Matter Segmentation of the Spinal Cord

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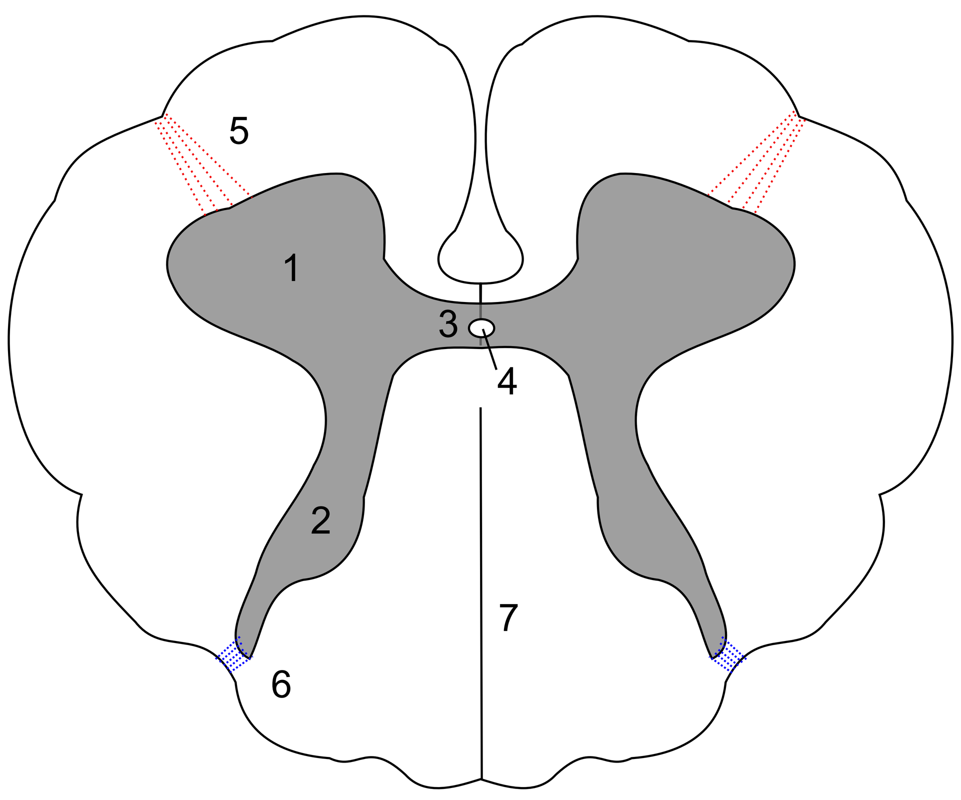
Introduction

In this study we address the problem of segmenting the inner structures of the spinal cord on MRI images. The spinal cord consists of surrounding white matter and inner grey matter with a cross-sectional butterfly shape (Fig. 1). Low resolution and low contrast between white and grey matter, even on 3D-PSIR images (Fig. 2), make this task difficult.



Grey matter
1 Anterior horn
2 Posterior horn
3 Grey commissure

White matter
4 Central canal
5 Anterior funiculus
6 Posterior funiculus
7 Median sulcus

Fig. 1: Schematic cross-section of the spinal cord.

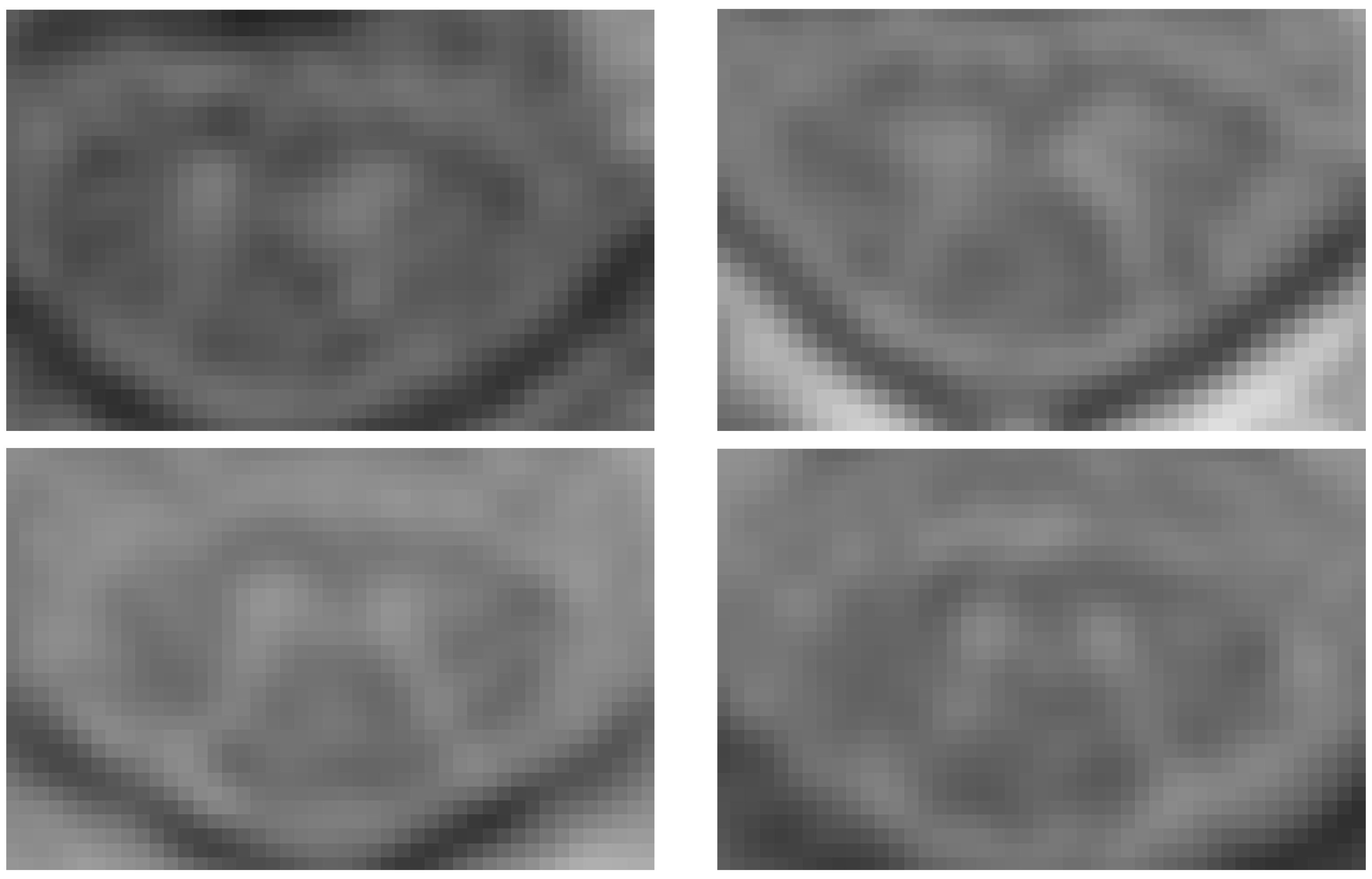


Fig. 2: 3D PSIR cross-sectional slices (0.4 mm × 0.4 mm).

The aim of this study is automated segmentation for the spinal cord to better understand the effect of multiple sclerosis on white and grey matter. The segmentation model should have the following properties: subpixel accuracy, robustness and automated localization of the spinal cord.

Results

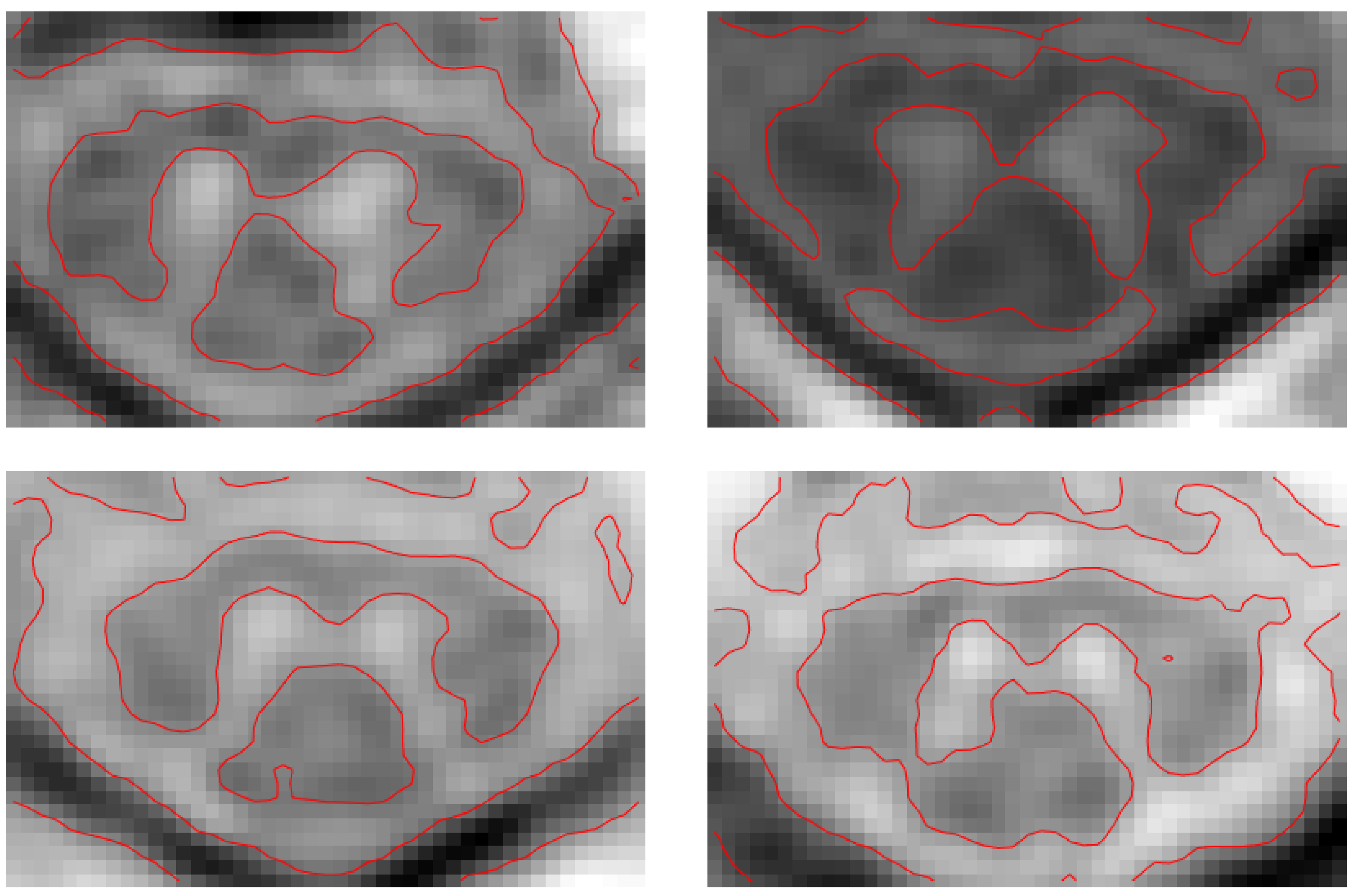


Fig. 3: Segmentation results of the current approach.

Math Background

In an abstract view we can describe a segmentation process as an optimization problem, where we define a functionspace V for the admissible labeling functions and an energy functional F with the optimal segmentation as minimal state:

$$\min\{F(u) \mid u \in V\}.$$

Numerically the functional optimization problems can be solved with iterative descent algorithms, whose steps can be seen as solutions of partial differential equations (PDE). So there exists a duality between the functional formulation and PDE based segmentation, connected by the gradient descent equation

$$\frac{\partial u}{\partial t} = -\frac{\delta F}{\delta u}$$

where δ stands for the variational derivative

$$\frac{\delta F}{\delta u} = \frac{\partial F}{\partial u} - \operatorname{div}\frac{\partial F}{\partial \nabla u}.$$

Model

Our task is to find appropriate integral operators for the functional by exploiting also the PDE formulations.
We follow the footsteps of Pezold *et al.*, who used continuous max flow formulations with carefully defined capacity constraints [1]. The formulations allow to segment the spinal cord as a whole by using statistical histogram information and tubularity features. For the grey matter segmentation we plan to develop a feature that detects butterfly shapes.
Our current approach (cf. Fig. 3) uses the following functional

$$\begin{aligned} F(C, \hat{I}_{\text{inner}}, \hat{I}_{\text{outer}}) = \; & \text{length}(C) + \\ & + \int_{\text{inside } C} \left|\tilde{I} - \hat{I}_{\text{inner}}\right|^2 d\Omega \; + \int_{\text{outside } C} \left|\tilde{I} - \hat{I}_{\text{outer}}\right|^2 d\Omega \\ & + \int_Z \sqrt{p_{\text{inner}}(z)\, p_{\text{outer}}(z)}\, dz, \end{aligned}$$

where C are closed curves in the image domain Ω, $\tilde{I}$ is a biased image, $\hat{I}_{\text{inner}}$ and $\hat{I}_{\text{outer}}$ are mean intensities of $\tilde{I}$ inside and outside of C and $p_{\text{inner}}, p_{\text{outer}}$ are the corresponding histrograms over the intensity range Z [2].

Acknowledgements

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References

[1] Pezold *et al.* Automatic Segmentation of the Spinal Cord Using Continuous Max Flow with Tubularity Features, 2015
[2] Wang *et al.* A novel level set method for segmentation, 2015