A Workflow Optimized Software Platform for Multimodal Neurosurgical Planning and Monitoring

Eine Workflow Optimierte Software Umgebung für Multimodale Neurochirurgische Planung und Verlaufskontrolle

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Purpose:
A neurosurgeon has to consider a variety of complex information in order to effectively plan and safely complete a brain surgery. He has to be aware of the location of risk structures, such as large fiber tracts, central blood vessels, and important functional brain areas, to the morphology of the target structure, such as a tumor of a certain type, size, shape, location, metabolism and structure. We present a novel software assistant for neurosurgical planning with special emphasis on an optimized workflow and efficient data exploration to support the surgeon in a time efficient, secure, integrative, and comprehensive manner. Such a system needs to facilitate a nonlinear and customizable workflow and to provide an intuitive user interface and fast access to the various modalities and findings. Moreover, uncertainties of algorithmic results, such as reconstructed fiber tracts, should be considered.

Method:
The platform comprises software modules for reviewing and exploring anatomical (T2, FLAIR, T1, pre/post-contrast), functional, perfusion, and diffusion tensor MRI. Our new configurable abstract descriptor system is a basis for optimization of complex workflows by choosing the most suitable data representation depending on the number and types of incoming data including user-defined arrangements of 2D, overlay, VRT, MIP, and MPR viewports.

A configurable automatic pre-processing pipeline comprises inter-sequence co-registration, intra-sequence motion correction, skull stripping, as well as fMRI pre-processing and analysis in order to minimize the amount of user interaction required before first results can be presented. The presented software provides additional tools to check the quality of the pre-processing step and to perform corrections if required. The fMRI quality check, e.g., allows to inspect the animated time series and to check for correlations between the underlying paradigm and motion estimates (cf. Fig 1). For time consuming registration tasks, such as fMRI motion correction, we have developed GPU based solutions and are able to speed up this task by a factor of five or more [1].

We further introduce universal data inspectors (UDI) (cf. Fig. 2-4) for a quick overview of and fast access to available data and results. It allows for manipulating essential properties of specific data objects like fMRI significance thresholds or color coding schemes. In addition it allows interchanging ROIs between different modalities, so that a region can be explored across data sets including useful statistical information and data-dependent operations. Tumors and other structures can efficiently be segmented on arbitrary images.

The variability in our DTI based fiber tracking is reduced by a novel variational scheme that adds small amounts of complex Gaussian noise to the images [2]. The remaining uncertainty of risk structure definition is visualized through appropriate safety margins. We propose a robust grid-based spectral fiber clustering algorithm [3] to improve the perception of and interaction with complex fiber sets. As for fMRI and DTI data, we also have integrated a perfusion review screen for assessment of various parameters describing the CBF/CBV.

Besides classical mesh rendering, we propose labeled volume rendering for 3D visualization. This allows interactively applying diverse rendering modes like different transfer functions or boundary and silhouette enhancements for each segmented object (cf. Fig 5).

Result:
We obtain a platform that facilitates the fusion of a variety of information in a comprehensible and flexible way. It provides a compact overview of the pathology and its functional and anatomical context as well as fast access to available modalities through the UDI. Preoperative identification of important risk structures is achieved by reliable analysis of perfusion, fMRI and diffusion tensor data.

Conclusion:
The optimized workflow and the minimized need for user interaction permits the efficient handling of the highly complex and multimodal data for neurosurgical planning and monitoring.

References:
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[3] Klein J, Ritter F, Hahn HK, et al. Brain Structure Visualization using Spectral Fiber Clustering. *SIGGRAPH* 2006, in print.

Figures:

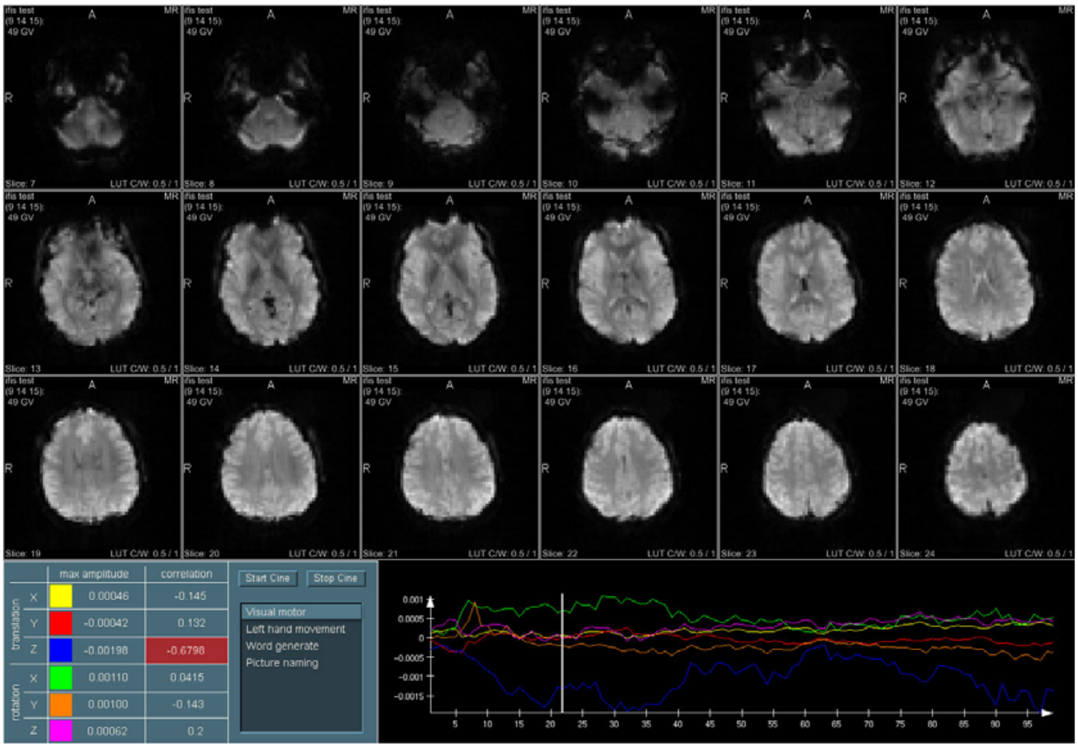

Fig. 1: fMRI quality check hanging; visual assessment of fMRI quality by investigation of animated time series plus motion estimates and additional information.

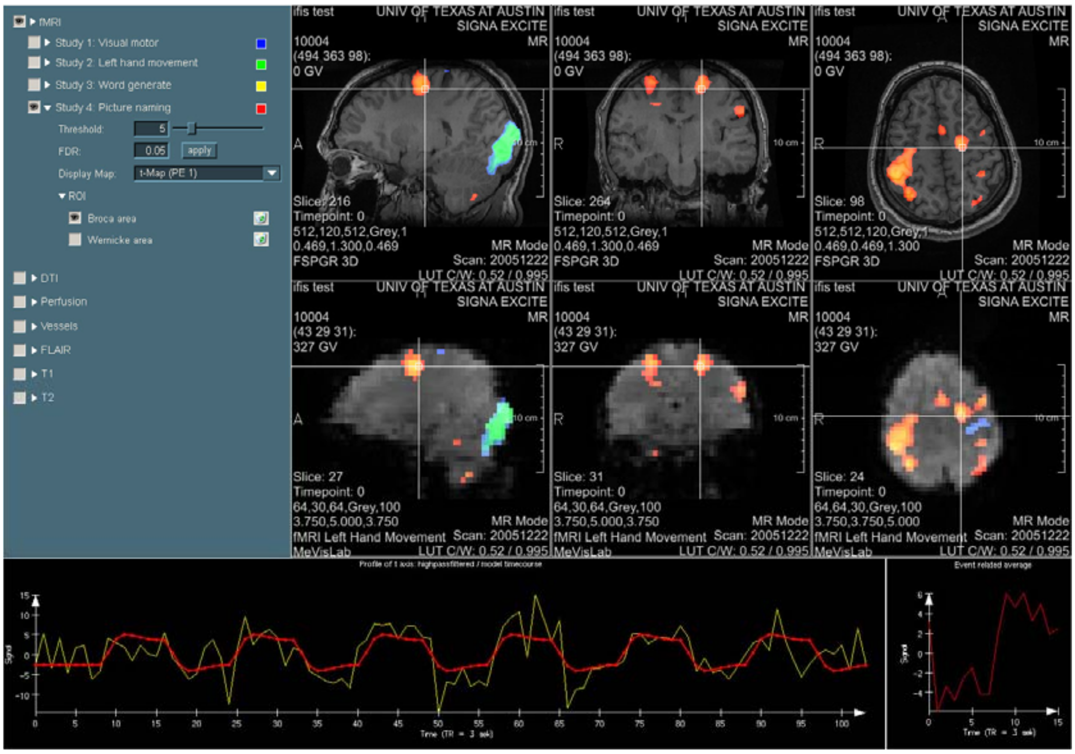

Fig. 2: fMRI review hanging; overlay view of activation map blended over anatomical and functional image; UDI to set various parameters such as ROI or t-map thresholds; ROI specific time course of data and model (bottom).

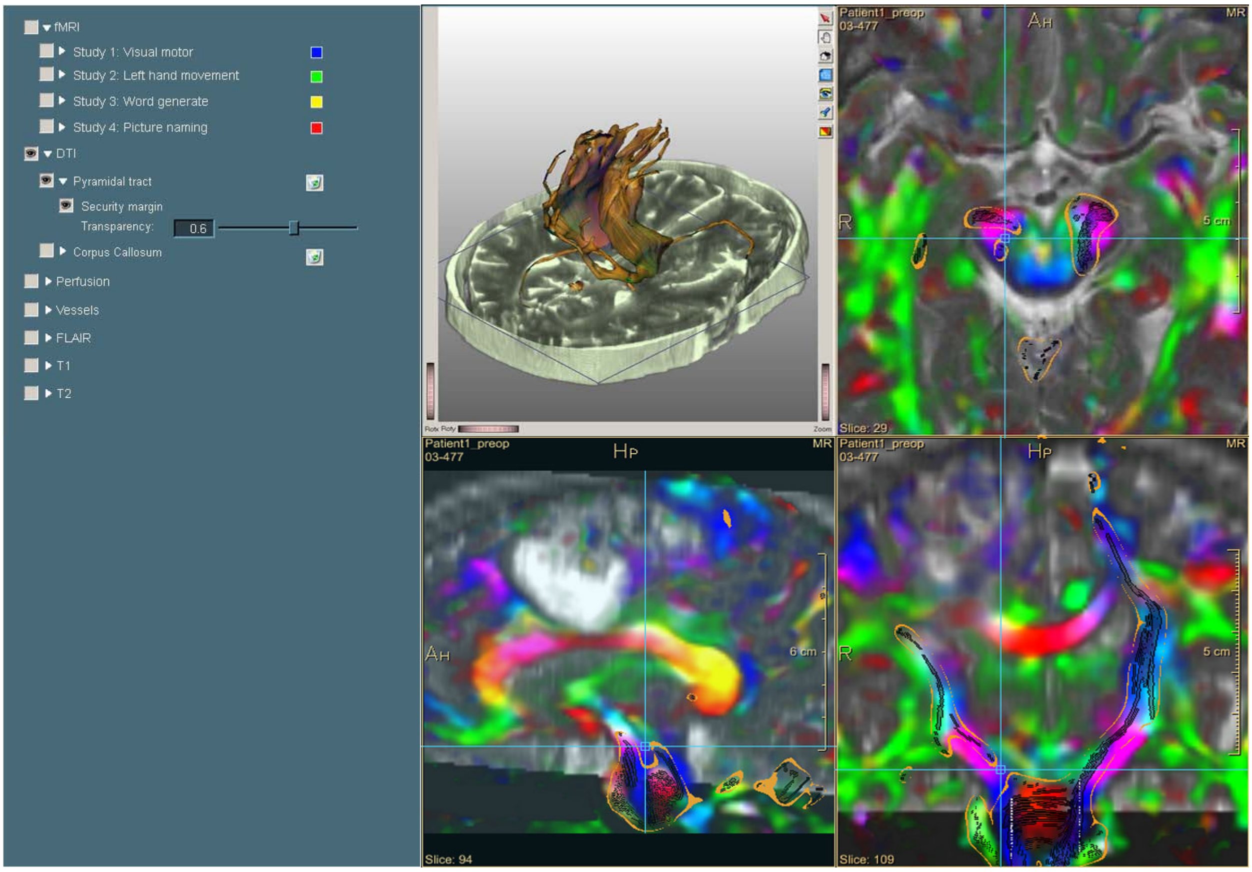

Fig. 3: DTI review hanging; three orthogonal views with an overlay of fiber tracts plus security margin; 3D rendering of the fiber bundle; note that only the fiber sets selected in the UDI on the left are shown.

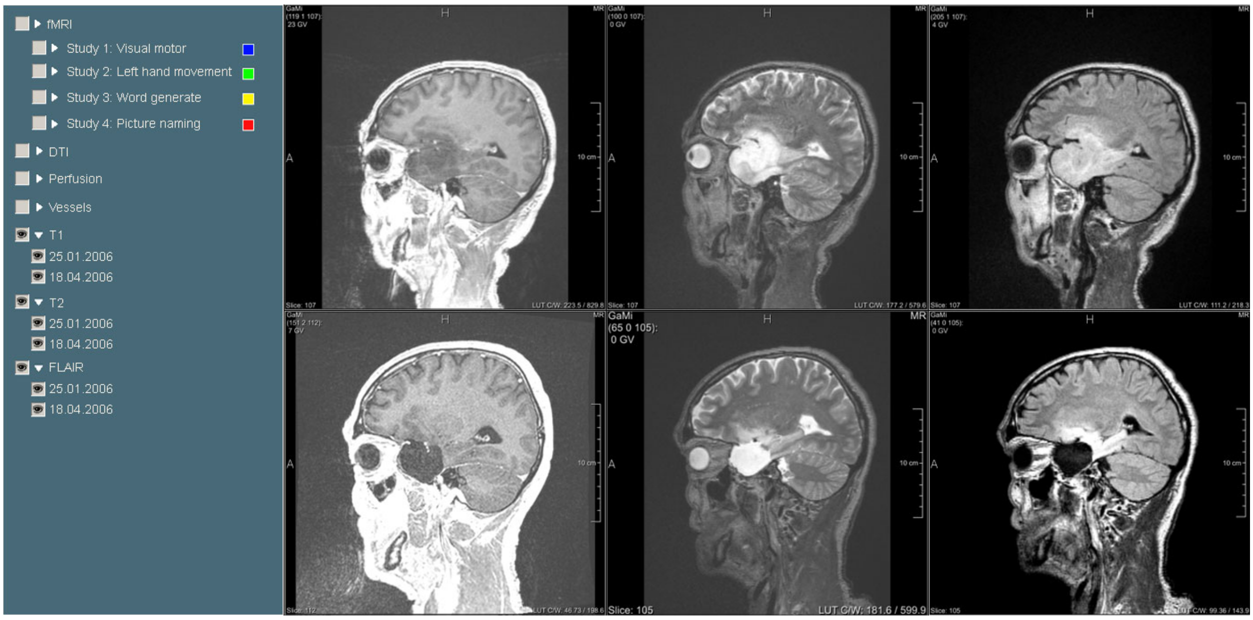

Fig. 4: Follow-up monitoring of a Glioma case; sagittal views of brain lesion before (top row) and after surgery (bottom); T1, T2, FLAIR weighted images.

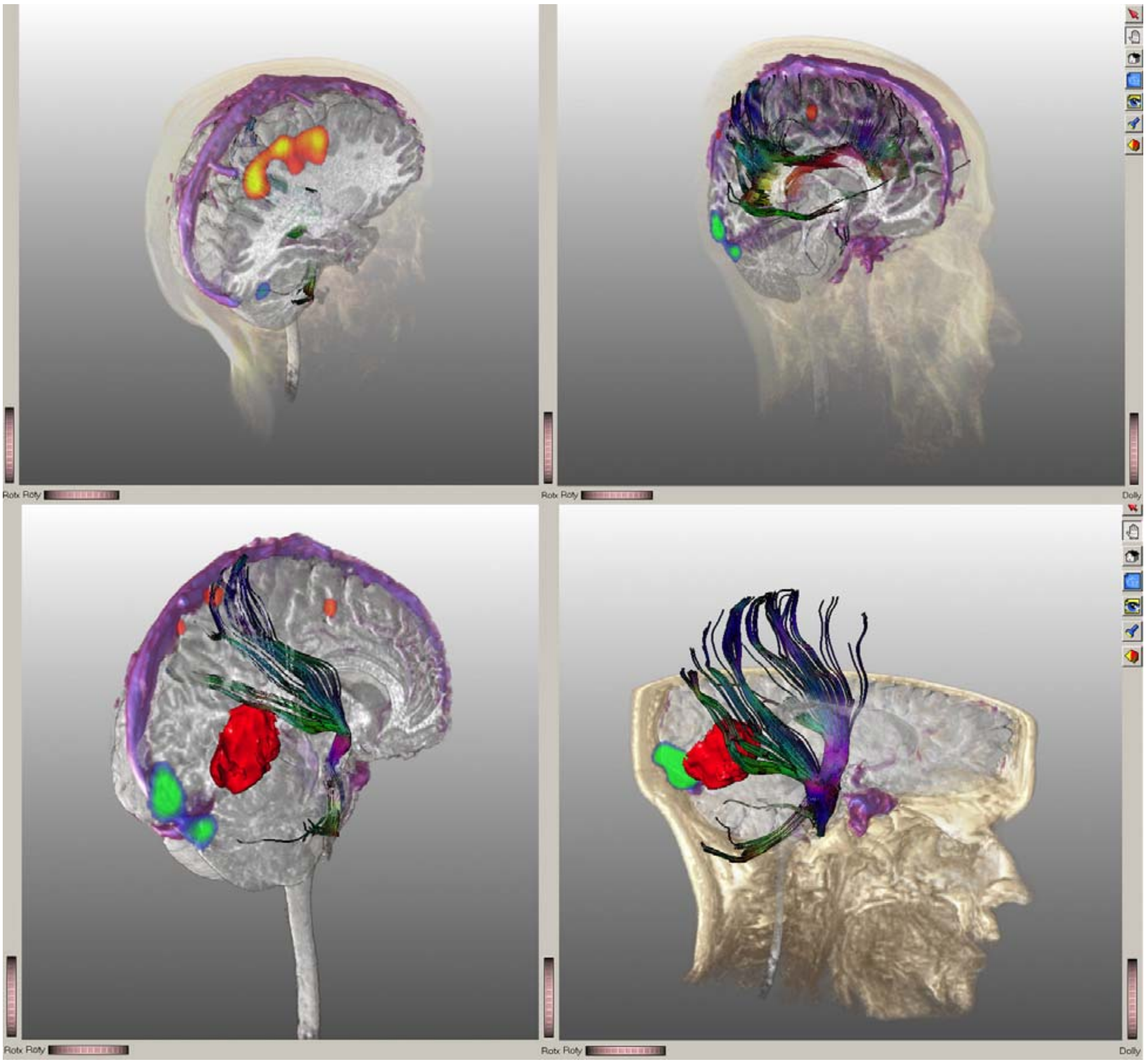

Fig. 5: Examples of combined interactive 3D rendering using a combination of labeled volume rendering and triangulated surfaces.