Chapter 1

Introduction and Summary

Rapid developments in 3D scanner technology have led to a major increase in the amount of information available to the physician. Image data are acquired using techniques like CT, MRI, Angiography (by *e.g.*, DSA, MRA or CTA), Ultrasound, SPECT, and PET. Furthermore, a scanner may support multiple acquisition modes, *e.g.*, T1, T2, and IR with MRI. While the image data can be collected in minutes, difficult cases may require hours of effort to decipher and understand. The traditional interpretation of the information using 2D images on a lightbox is therefore gradually being replaced by the analysis and visualization of images using medical workstations. This opens new posibilities for information processing and handling in order to support the clinician in his quest to interpret and understand the information.

Moreover, there is an increasing tendency to acquire information using multiple sources. The mental integration of the resulting multivariate data into a 3D representation of the patient is non-trivial. To alleviate this task, computer-aided techniques for integration of the information are called for. Integration consists of two basic steps, *viz.* registration or matching, and visualization or display. This thesis focusses on integrated visualization of volume data which is also referred to as fusion, hybrid visualization or synergistic visualization.

Integrated visualization is a broad theme comprising, *inter alia*:

- Integration of objects (such as surgical instruments and radiotherapy treatment beams) into a display of medical image data.
- Multiparameter visualization where different acquisition techniques of one imaging modality are used for information retrieval, *e.g.*, T1 and T2 with MRI.
- Multimodality visualization where information from different imaging modalities is integrated, *e.g.*, MRI and CT, or SPECT and MRI.

The subject of multimodality visualization can be further divided into the integrated visualization of data from two anatomical modalities, and of functional with anatomical data. This thesis focusses on the latter.

The purpose of this thesis is to study methods for integrated visualization of functional and anatomical brain images to enhance information retrieval from the multimodal data.

The anatomical information can be supplied by the patient's own anatomy using MRI or CT, or by a reference brain usually in the form of an anatomical atlas. Especially MRI is appreciated for its capabilities to differentiate between the soft brain tissues.

Functional information can be acquired by using appropriate radio-pharmaceuticals for SPECT and PET acquisitions, by means of fMRI, EEG, MEG, temperature measuring devices, special dyes, etc. We will focus on SPECT, PET and fMRI for the functional information.

Segmentation and registration are important prerequisites for integrated visualization, and errors introduced in these steps have a major effect on the fused images. Numerous groups are working in the field of segmentation indicating the enormous problems that are encountered. Our contribution to the field of segmentation is described in chapter 2 which introduces a method for completely automatic brain segmentation from MR–T1 images. This method is based on a supervised segmentation technique that combines 3D region growing and morphological operations (erosion and geodesic dilation). The latter technique was successfully used for segmentation in several projects. These experiences were the motivation for the development of a method that removes all user-interaction by transferring the decisions to a computer algorithm. The method is qualitatively and quantitatively evaluated for visualization purposes using both phantom and patient data. The results show that the method yields accurate and reproducible segmentations of the brain from MRI–T1 data. Although this chapter on segmentation is based on experiences gained throughout the PhD study, and in fact was written as the last chapter of the thesis, it is discussed first, because it describes a preprocessing step for the principal subject of the thesis, *i.e.*, visualization.

A brief overview of the recent developments in the area of registration is presented in the first part of Chapter 3. Several characteristics are used to categorize the different methods which yields a clear preference for intrinsic, voxel based matching. The second, and more extended part of this chapter gives an overview of different methods for integrated visualization garnished with own experiences and illustrations. The task, observation, and observer dependencies preclude a generic conclusion, but it appears that several techniques are quite appropriate for multimodal brain image fusion.

Chapter 4 presents a technique for integrated 3D visualization of functional and anatomical data. This technique is named Normal Fusion because it projects regional information sampled along the inward normal of a surface onto the surface. This chapter explains how functional information of the surface layer of the brain, acquired using SPECT can be color encoded onto the brain surface as extracted from MRI data. A brief qualitative evaluation is included in this chapter indicating that the Normal

Fusion technique provides a potentially comprehensive and diagnostically valuable presentation of cerebral blood perfusion in relation to the anatomy of the brain.

Chapter 5 is an extension of Chapter 4 in that the Normal Fusion is used as a tool to evaluate the use of the HSV color model to allow color manipulation of an integrated 3D visualization. This approach can be applied for numerous visualization techniques, but here we focus on the implications for the surface mapping of functional activity using the Normal Fusion method. Several clinical examples are presented to show the feasibility of the approach, while experiences in a clinical setting are discussed. Results show that the use of the HSV color model for integrated 3D visualization allows easy, rapid, and intuitive retrospective manipulation of the color encoding of the functional information. Furthermore, the clinical evaluation demonstrates that this approach is an important asset in the investigation of data from multiple modalities.

Chapter 6 discusses a validation study to investigate the possible value of integrated visualization methods in clinical practice. 2D SPECT display and three methods for integrated visualization of SPECT and MRI are evaluated by a multi-observer study using 30 patient sets. Nuclear medicine physicians performed a localization task and also rated their confidence of the observation. Inter-observer agreement using kappa statistics and average confidence ratings were assessed to interpret the reported observations. The results show that integrated display of functional and anatomical brain images improves localization of functional abnormalities in relation to the anatomy and increases the confidence of the observers in their localizations.

Chapter 7 is a preliminary qualitative interpretation of 3D fusion for clinical cases. The SPECT and MRI data of two patient groups, *i.e.*, cases diagnosed with the Gilles de la Tourette Syndrome and Attention-Deficit Hyperactivity Disorder, are presented using the Normal Fusion technique. These fusion images are first compared with the 2D SPECT images to assess whether Normal Fusion accurately characterizes the functional data of the cortical surface layer. Then the fusion images of the individual cases are qualitatively evaluated and the two patient groups are compared. The results indicate that the signaling of cortical activity by the Normal Fusion images is in good agreement with 2D SPECT reconstructions and that specific patterns of hypo or hyperactivity are more easily recognized with the Normal Fusion technique.

In summary, this thesis demonstrates that integrated presentation of the functional and anatomical brain images is a powerful tool in retrieving relevant information from the data contained within the original 2D image slices. Evaluation of the different fusion techniques performed in several chapters indicates that the diagnostic process improves, notably as concerns the localization of functional processes, speed of comprehension, and communication with referring specialists. Furthermore, the fused images are able to both present multivariate information succinctly and highlight specific aspects. Finally, the flexibility of the presentation not only aids the diagnosis, but also helps to raise new hypotheses on functional brain processes in relation to the underlying anatomy.