EDITORIAL

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This special issue is devoted to the topic of Processing, Analysis, and Understanding of Magnetic Resonance Images (MRI) of the Human Brain. Since its inception as a clinical diagnostic procedure in the early 1980s, magnetic resonance imaging has rapidly risen to become the method-of-choice for numerous clinical, diagnostic and research purposes. The interactions of nuclei which exhibit specific magnetic properties (such as hydrogen) with strong magnetic and radiofrequency fields have resulted in the development of imaging systems with an exceptional range of sensitivities. In imaging the brain, MRI has shown the ability to provide sub-millimeter resolution for the visualization of normal anatomy, the detection of pathologic changes, and the elucidation of functional and physiologic properties.

During this same short period there have been concurrent and equally dramatic advances in desktop signal and image processing capabilities. Today's computer workstations have surpassed the capabilities of the supercomputers of the early 1980s, and have done so at costs well within the reach of average clinical and even classroom settings. The ubiquity of such low-cost, general purpose computational platforms has transformed the field of signal and image processing, allowing the practical implementation of a far greater range of existing algorithms, and spurring the development of new classes of algorithms. Such expanding interest in image processing has also led to an explosion of interaction between such fields as computer vision, automatic target recognition, artificial intelligence and neural networks, and the associated investigation of new processing paradigms. Collectively, these enabling technologies have substantially increased the degree to which "intelligence" can be incorporated into various data processing tasks, and therefore the usefulness of the processing results has improved dramatically.

Finally, the field of neuroscience has evolved at an equally accelerated pace, into a full fledged assault on the secrets of how the brain works throughout the entire

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spectrum of scales, from the molecular, to the cellular, to the neuron-systemic, through the macro-behavioral. It is certainly with these factors in mind that the 1990s have been designated as the "Decade of the Brain." This designation reflects the hope and promise provided by the above enabling technologies for a vastly improved understanding of the great mystery that is the human mind.

As a part of this enterprise, many investigators have been attempting to extract more and more information from the increasing volumes of MRI brain data being produced. This data contains a wealth of information regarding details of the structural makeup and functional properties of the human brain — albeit at a level which presently requires considerable effort to extract. The utility of this information has long been appreciated at a qualitative level — indeed, one of the immediate attractions of MRI imagery is the enticing clarity with which it seems to allow us to peer into the brain. To take the inferential power of this information to the next level, however, more automatic and precise quantitative treatments of this data are needed. It is to this end that the editors of this special issue have sought to assemble a cross-section of these developing techniques which promise to play a vital role in maximizing the information extracted from MRI imagery and thus our understanding of the human brain. These methods and their applications span a wide range of research topics which combine the use of magnetic resonance imaging and the study of human brain science. The potential impact of these methods on the routine use of such quantitation, the development of novel, more informative types of clinical measures, and the enhancement of clinical care through the diagnostic and prognostic abilities which can be conferred is great.

The articles contained herein are grouped with respect to the process of neuroanatomic image segmentation from the MRI data, and the application of these results in the clinical setting. The articles pertaining to neuroanatomic segmentation begins with a paper by Worth *et al.*, which presents an overview of the neuroanatomic segmentation problem, with particular attention to the details which complicate practical implementation. The issues foreshadowed by these complications provide the underlying motivation for many sophisticated algorithmic tools which are developed, and approaches which are taken, in the subsequent papers. This introduction is followed by five papers which explore methods to effect the segmentation and characterization of MRI data sets of the human brain.

First, the paper by Pham and colleagues focuses on the signal intensity characteristics of the tissues of the brain. In addition to being of interest in their own right, such characterizations provide the statistical information necessary for the formation of prior models of intensity. The knowledge and use of such reliable prior information can greatly improve the outcome of automated or semi-automated processing. The derivation of joint statistical characterizations of tissue types and acquisition parameters arising in the intensities in MRI data sets has been lacking, and thus such results are greatly needed.

The next paper by Kaufhold *et al.*, explores a recursive estimation approach to segmentation of MR images. This approach provides a computationally tractable means for segmenting large MRI datasets within a statistical context, while simultaneously estimating the associated measures of uncertainty. Such measures are typically not provided in the segmentation, yet they are important for evaluation and subsequent fusion tasks.

Following this, Pien *et al.*, present a segmentation approach that combines both variational snakes and curve evolution within a single framework. The method allows the incorporation of prior information concerning the location of edges in the form of a set of deformable models for the edge structure. The use of such prior information is critical, as many neuroanatomical brain boundaries are weakly visible in MRI data or are not intensity based at all. In such cases, prior information must be used to supplement the observed data if reliable anatomical region labeling is to occur.

The theme of incorporating prior shape information in the form of a deformable template is continued in the work by Staib *et al.*, where a gradient-based deformable surface model is presented. Experimental results on synthetic and MR brain images demonstrate the significant improvement conferred by the additional constraints of gradient-based models. Such models also serve to robustly account for normal variation. Note that the prior information in this case is contained in the continuous nature of the fitted surface together with an imposed bias toward shapes that are more likely to occur.

Finally, the general anatomical segmentation theme is brought to a close in a contribution from Collins *et al.*, where the segmentation problem is posed as a problem of nonlinear registration of a previously segmented target brain. By posing the segmentation problem in this way, complex non-intensity boundaries and detailed volume labels can be accurately identified and mapped. Prior knowledge in this case is directly captured in the target brain.

The next two papers focus on the cortical folds defining the surface of the brain. The paper by Le Goualher and colleagues model the cortical surface using active ribbons, a surface-based extension to the active contour, or snake, formalism. These active ribbons are used to represent the surface folds, which also yield a segmentation boundary that separates the gyri from the sulci based on a curvature analysis. And while most methods treat the precise identification and localization of cortical sulci as part of the more general tissue classification problem, this paper acknowledges the subtle difficulties of accurately labeling the cortex by providing a specific model for its segmentation. This procedure can be used to aid visualization, model inter-subject variability, constrain electro-magnetic recording solutions, and control local nonlinear warping schemes.

Following this, the paper by Joshi *et al.*, presents a method for performing geometrical characterization and the analysis of the brain surface. This is accomplished through the construction of detailed surface coordinate systems of the cortical structure. Such a construction allows the creation of surface property maps, such as curvature and shape. The potential use of such maps is demonstrated through the definition of features which distinguish normal and schizophrenic hippocampi. In this work, the statistical models are built not on the pixel intensities themselves, but rather on the set of underlying geometric transformations. Furthermore, statistical models of both the average and the variation of neuroanatomical shapes provide prior information that is necessary to achieve the next level of accuracy in the analysis of MR brain images.

The final two papers transcend the analysis of the image of a given individual at a specific time. First, the paper of Guimond *et al.*, discusses the creation and exploration of a MRI database. Specifically, methods for retrieving corresponding volumes from multiple subjects, and the creation of average representations of the morphology which characterize these populations, are presented. Coupled with classification and registration techniques, this paper introduces one method to deal with the informatics issues that arise in MRI data utilization.

The final paper of this issue is contributed by Grimson *et al.* and demonstrates how the results of the various processing tools of segmentation and registration can be used in the enhancement of MRI image-guided surgery. Here segmented MRI data provides the foundation upon which interactive, inter-operative information can be collated. Developments in this area may indeed make it feasible to provide real-time dynamic MRI-based feedback to the surgeon in the context of minimally invasive interventions.

The editors also have solicited a closing commentary and perspective on the future impact of these and related developments in the burgeoning neuroscience community. This commentary has been provided by Dr. Michael Huerta, Associate Director, Division of Neuroscience and Behavioral Science at the National Institute of Mental Health, and co-organizer of the Human Brain Project, an interdisciplinary, interagency effort to foster communication and informatics across all scales, modalities and species within the neuroscience community. Dr. Huerta's commentary speaks to the relationship between brain imaging and the complexities of brain research, as well as the multidisciplinary efforts necessary to advance the field of neuroinformatics.

We would like to express our thanks to the many individuals that have contributed to this special issue. Without the efforts of these many colleagues, this issue would not have been possible. We hope that we have successfully compiled, in one issue, an insightful and informative collection of research demonstrating the in vivo visualization, analysis, and characterization of human brain data with respect to health and disease, development and aging, and structure and function. Additionally, we hope that we have been successful in conveying the sense of excitement that surrounds the application of intelligent data processing techniques to increasing our level of understanding of the functionalities of the human brain. While it is unfortunate that we cannot include papers on other worthy and relevant topics — including fMRI, diffusion-weighted MR, and MRA — we nonetheless are hopeful that this "tip of the iceberg" view of the intersection among image processing, artificial intelligence, and neuroscience proves useful.