MULTI-DIMENSIONAL IMAGE PROCESSING, RECONSTRUCTION, VISUALIZATION AND ANALYSIS: TECHNOLOGIES AND APPLICATIONS

Medical Image Processing Group
University of Pennsylvania
Department of Radiology
Philadelphia, Pennsylvania – 19104-6021
Contact Jayaram K. Udupa: jay@mipg.upenn.edu

The technologies developed and the applications currently pursue by us are listed under two separate headings.

- **Technologies**
- **Applications**

TECHNOLOGIES

- **Image Visualization and Image Processing**

    1. ***3DVIEWNIX***
    2. ***MR Image Intensity Standardization***
    3. ***Inhomogeneity Correction/Filtering***
    4. ***Fuzzy Connectedness***
    5. ***Registration***
    6. ***Model-Based Image Segmentation***
    7. ***Evaluating Image Segmentation Methods***
    8. ***Visualization***
    9. ***3DVIEWNIX-AVS***
    10. ***3DVIEWNIX-TV***

- **Image Reconstruction in Positron Emission Tomography**

TECHNOLOGIES

1. 3DVIEWNIX

It is a software system for the processing, visualization, manipulation and analysis of multidimensional images.

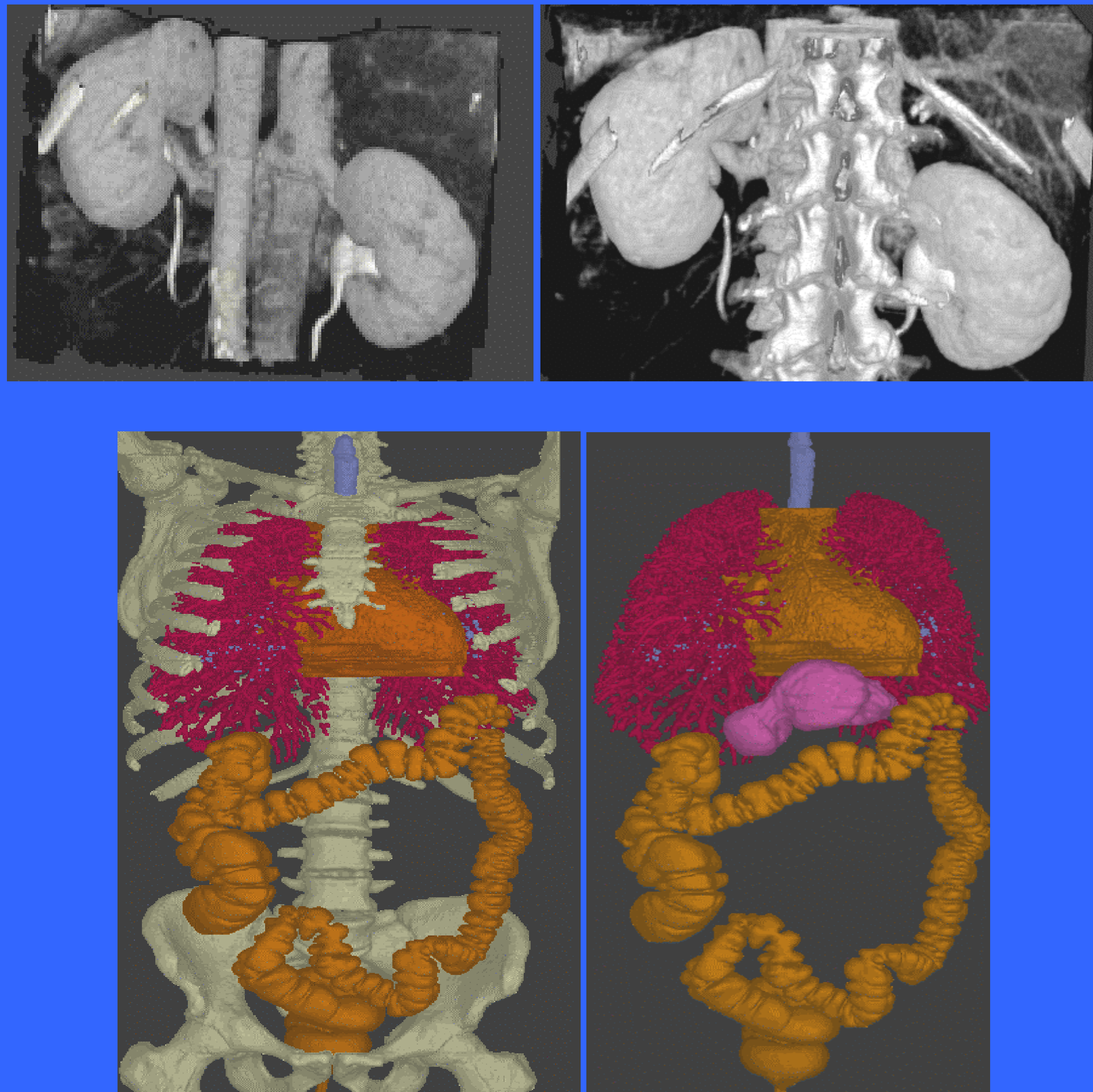
Over 40 person years of work in it and used at 100s of sites worldwide.

A comprehensive system with numerous functions including image filtering, image interpolation, image segmentation, image registration, image algebra, various forms of slice display, surface and volume rendering, 3D object manipulation (including cutting, separating, mirror reflection, and editing) object registration, various forms of image and object analysis (including ROI statistics, density profile, volume, area, distance, length, kinematics).

Forms the core of our other technologies and all applications.

(See www.mipg.upenn.edu for more information)

Team: J.K. Udupa, D. Odhner, G.J. Grevera, P.K. Saha, L.G. Nyul and over 20 past members of MIPG.



Some examples of the types of visualizations created by 3DVIEWNIX, in this case from Imatron Cine CT.

2. Fuzzy Connectedness

Image segmentation is the most fundamental yet the most difficult among all image processing, visualization, and analysis operations.

Fuzzy connectedness is a radically different approach to image segmentation in that it considers object material heterogeneity, imaging noise, and blurring in its design.

Has proved effective and hence used in most of our applications. Has potential in any application requiring object delineation in images.

A family of approaches including scale-based, relative, iterative, vectorial and model-based fuzzy connectedness pursued at present. These methods and their applications have been published extensity.

Team: J.K. Udupa, P.K. Saha, D. Odhner, L.G. Nyul, Y. Zhuge, T. Lei, and J.G. Liu.

3. MR Image Intensity Standardization

MRI intensities vary even for the same tissue in the same body region in the same patient on the same scanner when imaged at different times.

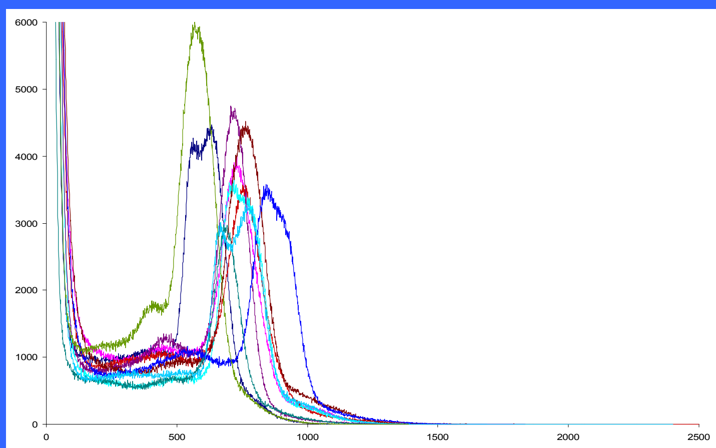
Intensities lack a tissue-specific quantitative meaning unlike in CT. This causes problems in image display and image analysis.

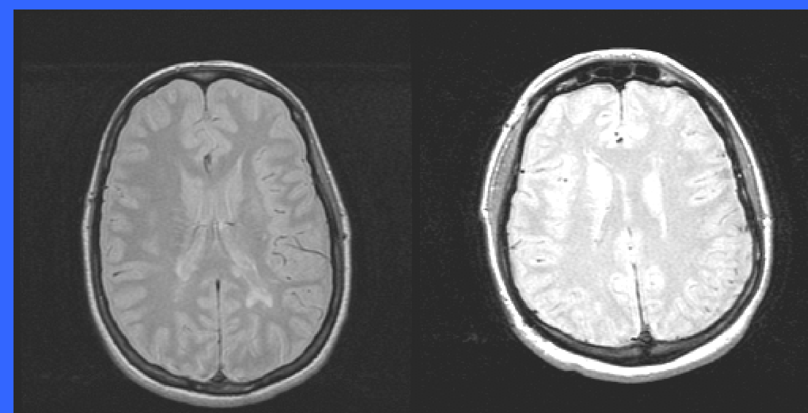
Our histogram deformation method produces a standard scale overcoming these problems. Numeric tissue characterization becomes possible. Image display and analysis are greatly facilitated upon standardization.

Team: J.K. Udupa, L.G. Nyul, and A. Madabhushi.

Image Intensity Standardization: Histograms of 10 FSE PD brain volume images of MS patients (a). The histograms after standardization (d). Original slices from two studies MR acquired as per the same FSEPD protocol before standardization displayed at default windows (b, c), and after standardization displayed at a fixed "standard" window (e, f).

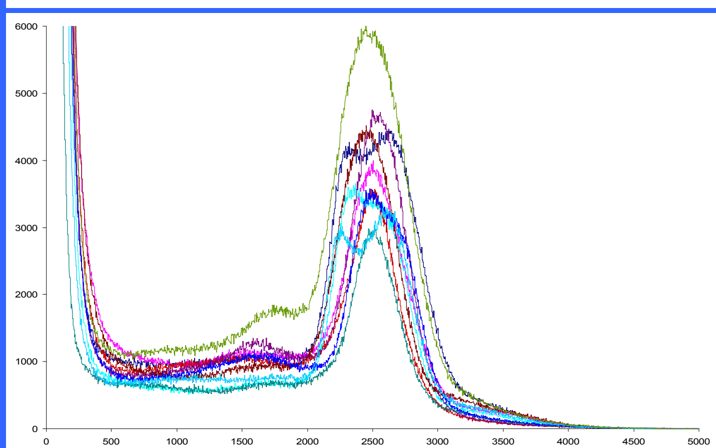
(a)

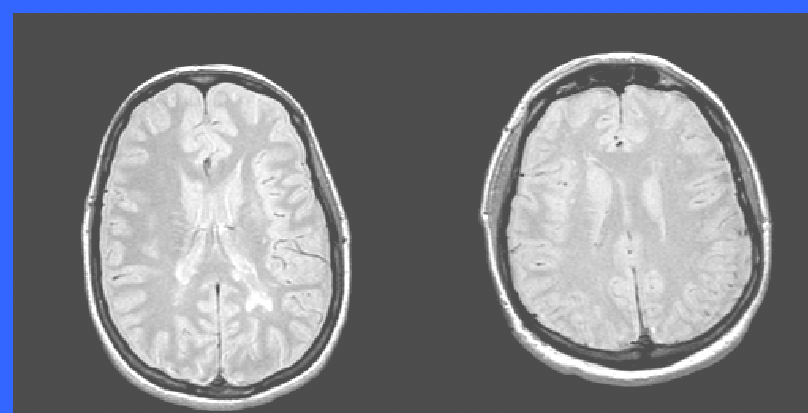




(b) (c)

(d)





(e) (f)

4. Inhomogeneity Correction/Filtering

To develop scale-based (*b*-scale, *t*-scale, *g*-scale) methods for image processing, particularly for correcting image inhomogeneities due to magnetic field non-uniformities, and for non-linear image filtering.

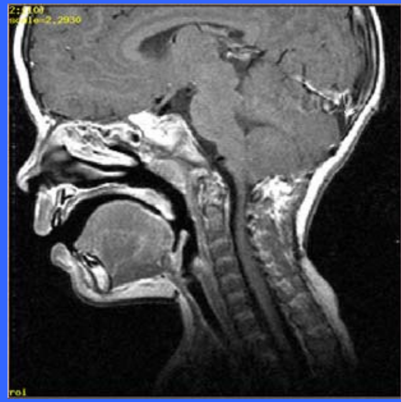
To determine the best order of processing for standardization, inhomogeneity correction, and filtering.

Protocol independent inhomogeneity correction that does not require prior knowledge of tissue intensity distribution.

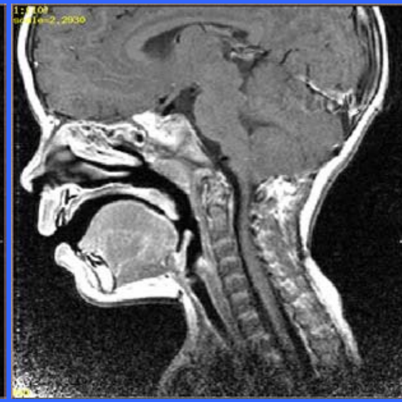
Scale-based filtering strategies that are more effective than anisotropic diffusion.

Team: J.K. Udupa, P.K. Saha, J. Liu, Y. Zhuge, A. Madabhushi, A. Souza, and A. Montillo.

Inhomogeneity Correction



Before

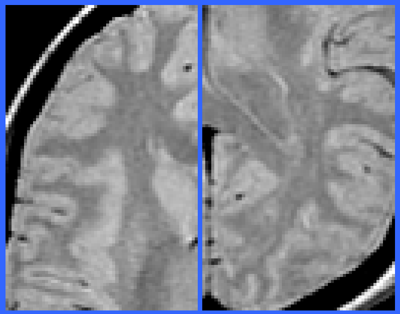


After

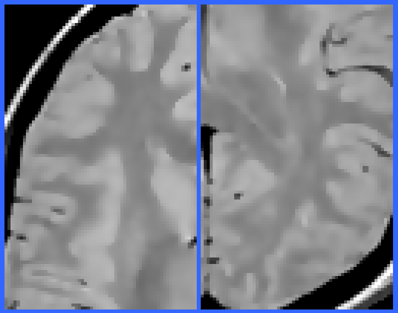
Before

After

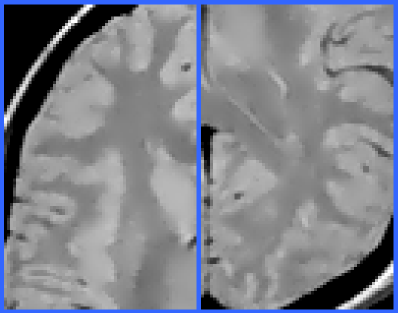
Filtering



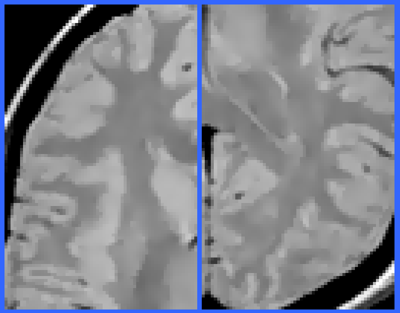
Original



Anisotropic Diffusion

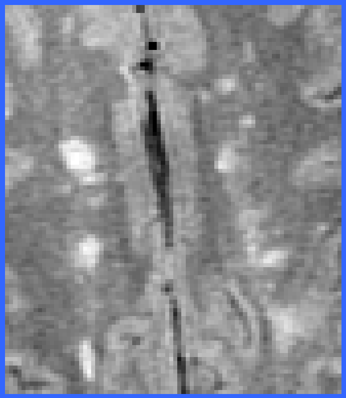


Scale-Based Averaging

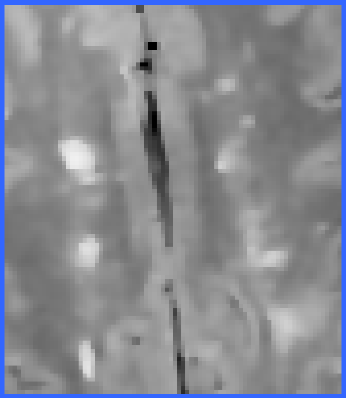


Scale-Based Diffusion

Filtering

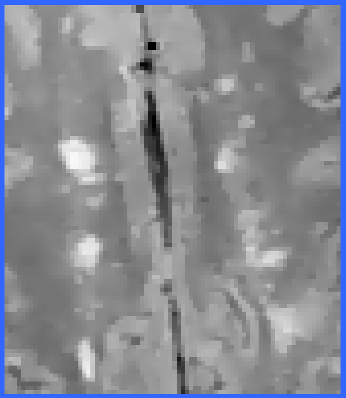


Original



Anisotropic Diffusion

Scale-Based Averaging



Scale-Based Diffusion

5. <u>Image Registration</u>

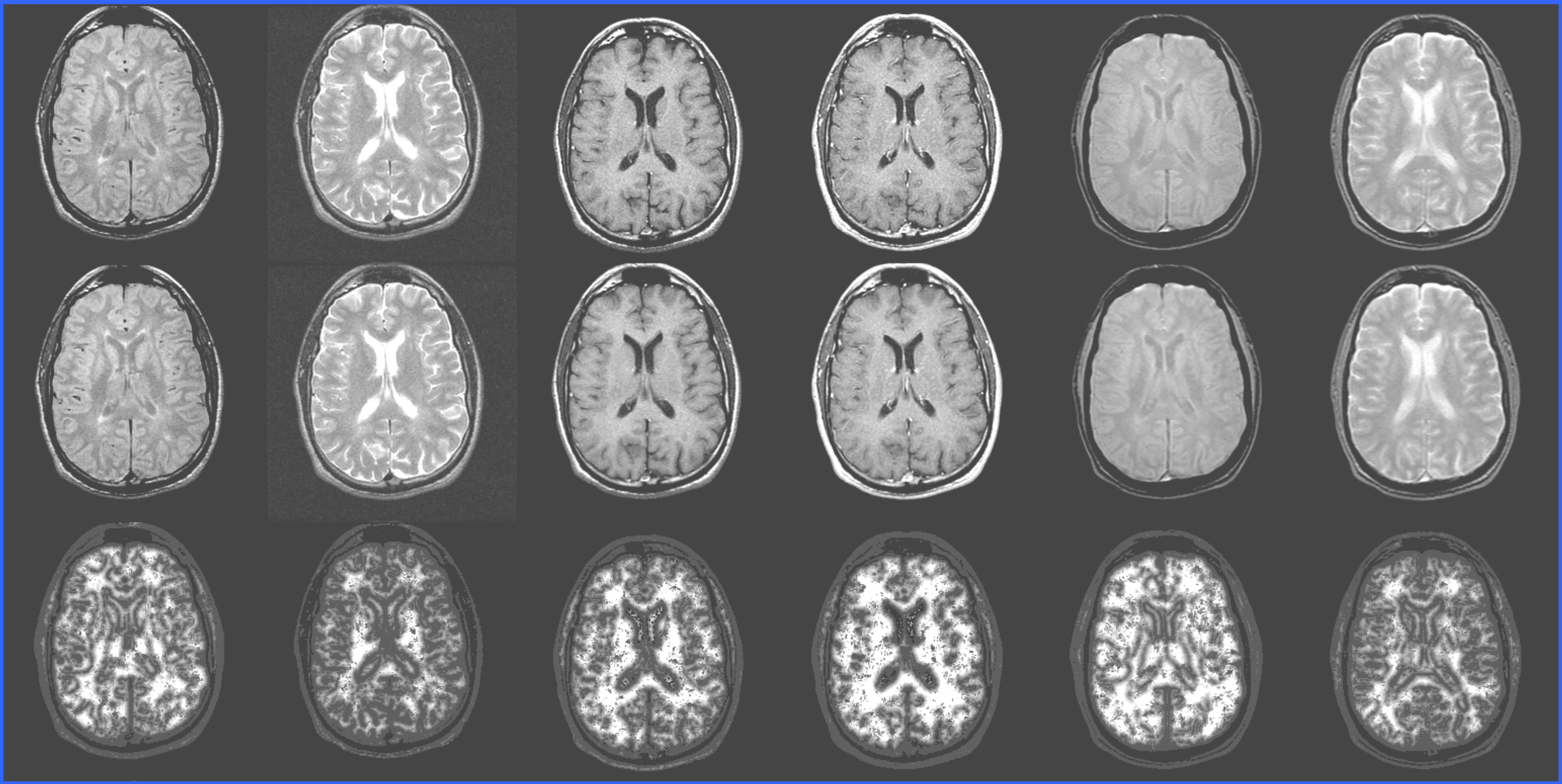
To develop rigid and deformable registration strategies for representing multimodality images in the same coordinate system.

Scale-based rigid registration for matching multiprotocol MR images of MS patients.

Deformable registration of multiprotocol, multidimensional breast images

Team: J.K. Udupa, G.J. Grevera, P.K. Saha, L.G. Nyul and M. Schnall.

Result of Registration



Top: PD, T2, T1, T1E, MT1, MT2 – Original.

Middle: PD, T2, T1, T1E, MT1, MT2 – After Registration.

Bottom: PD, T2, T1, T1E, MT1, MT2 – Scale Images.

6. Model-Based Image Segmentation

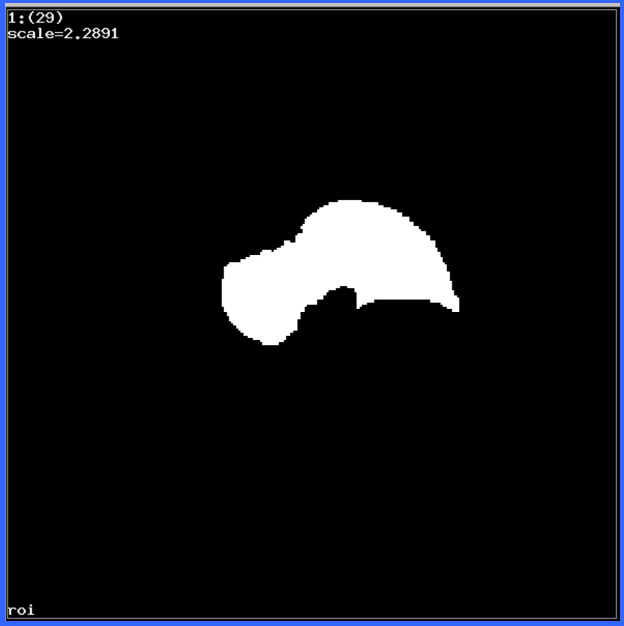
To develop model-based strategies for tackling object delineation in difficult segmentation situations.

When images are taken for different positions of an organ, such as of a joint, use the segmentation in one position as a model to segment the same object in another position.

Active shape and appearance models being developed and investigated in conjunction with other segmentation strategies.

Team: J.K. Udupa, J. Liu, A. Souza, P.K. Saha, and Y. Zhuge.

Position 1 Image



Segmentation for Position 1

Position 2 Image with Position 1 Segmentation

Position 2 Image with Position 2 Segmentation

7. Evaluating Image Segmentation Methods

To develop a framework complete with real clinical image data, their true segmentations, several standard segmentation methods, evaluation metrics and methods, and software that incorporates all these.

Team: J.K. Udupa, Y. Zhuge, C. Imielinska, H. Schmidt, and V. LeBlanc.

8. Visualization

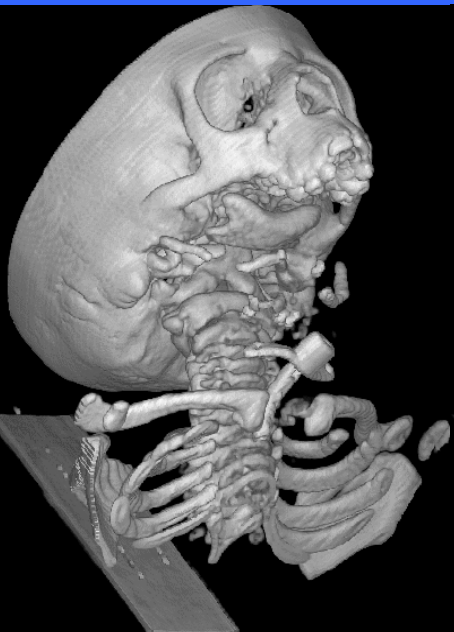
To develop improved strategies for surface and volume rendering.

Combine the storage efficiency of shell rendering with the speed efficiency of shear-warp method to develop very efficient shear-warp shell rendering.

Utilize the high-speed rendering capabilities of digital methods (such as shell rendering) to render entirely in software large triangulated surfaces (without decimation) at substantially higher speeds than that on specialized rendering hardware.

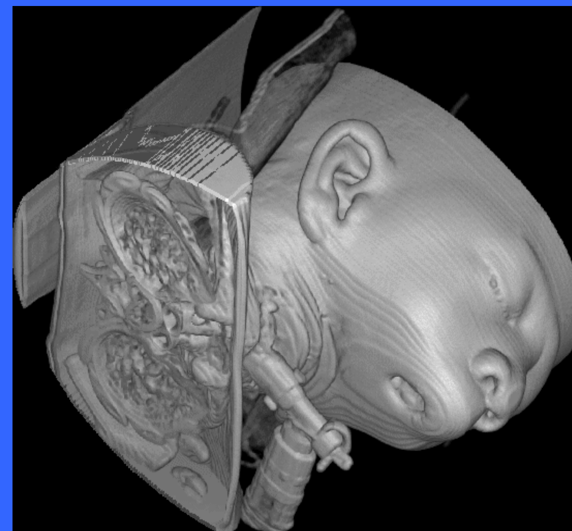
Address partial volume effects in volume rendering to remove pseudo interfaces.

Team: J.K. Udupa, G.J. Grevera, D. Odhner, A. Souza, and A. Falcao.

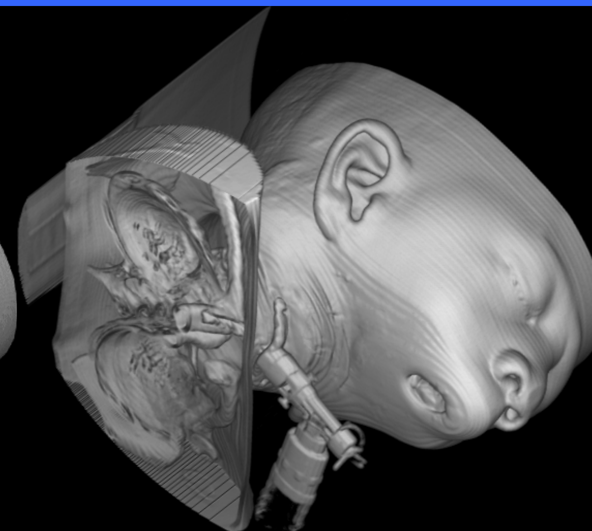


Shear-Warp Shell

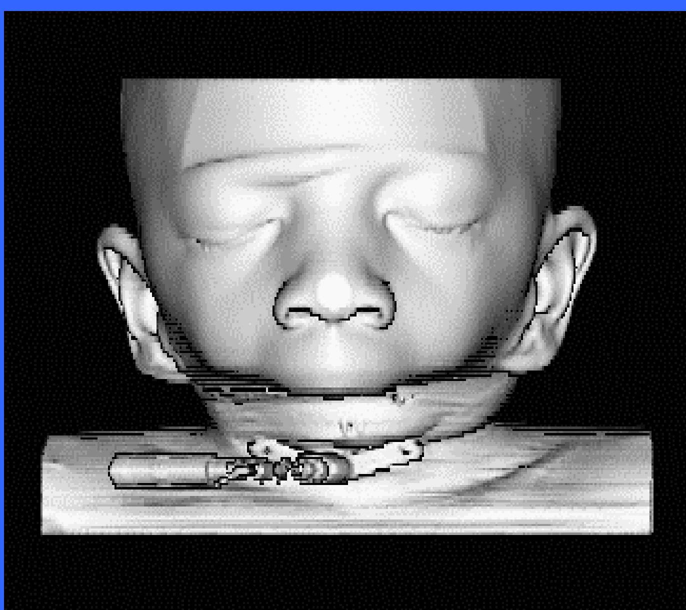
Shear-Warp



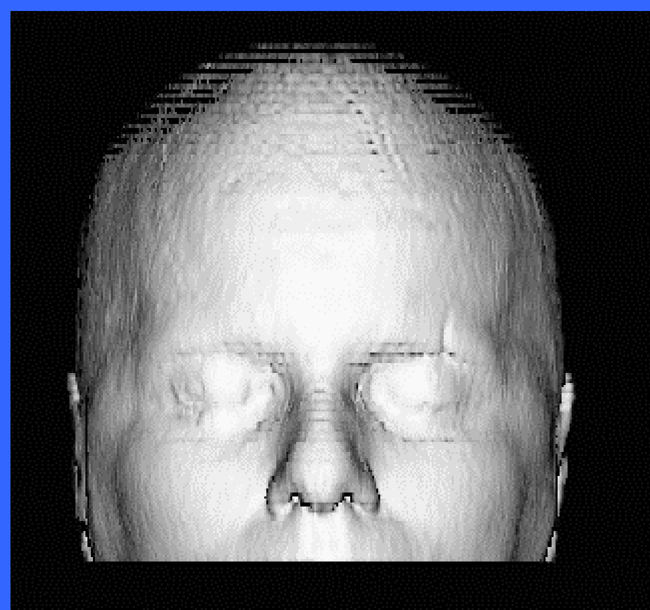
Shear-Warp Shell



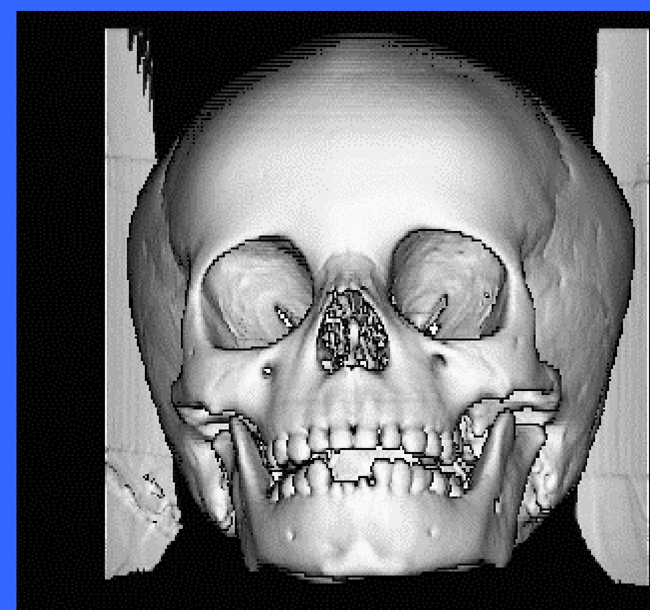
Shear-Warp



Triangulated Shell Rendering

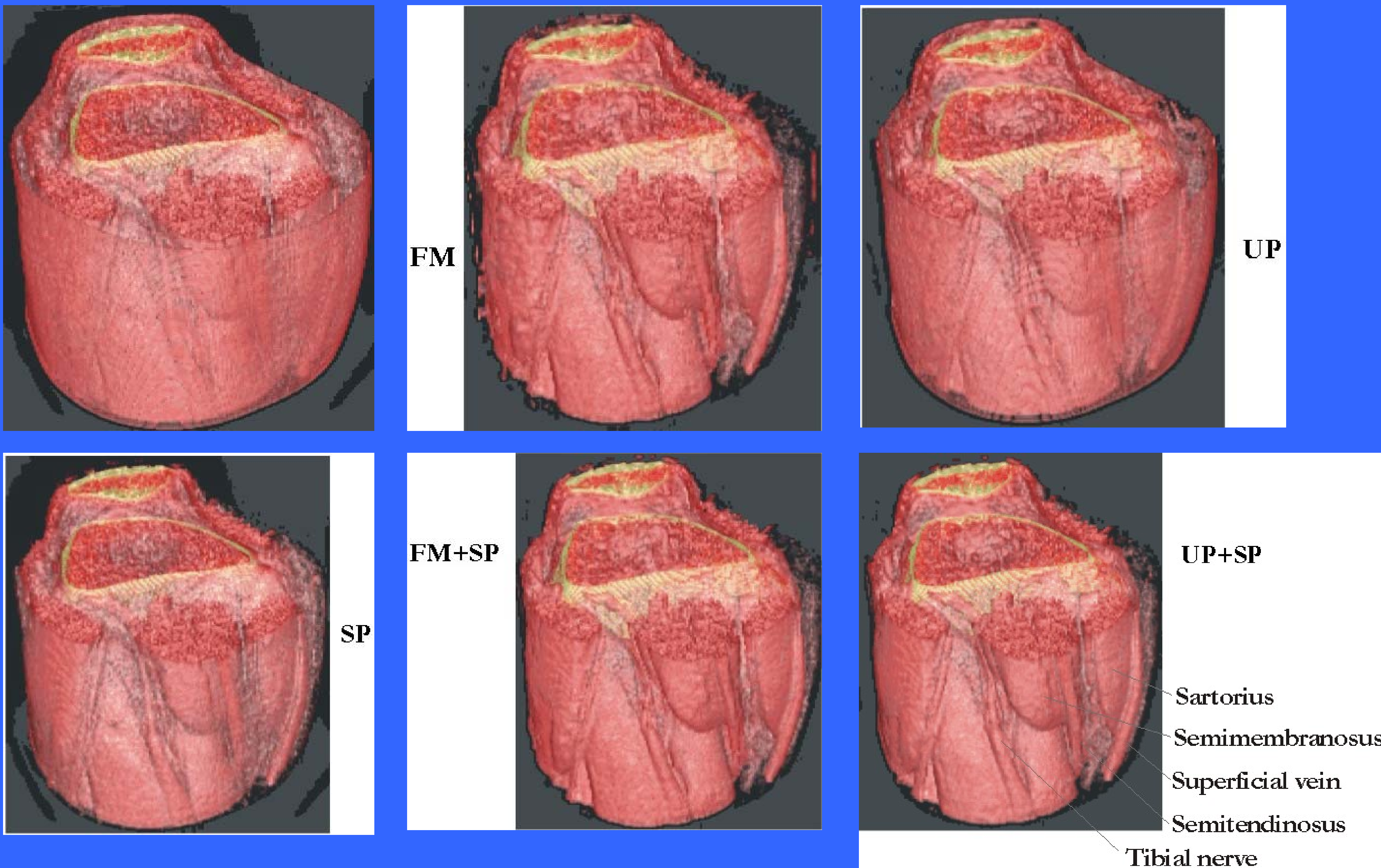


Triangulated Shell Rendering



Triangulated Shell Rendering

Removal of Partial Volume Effect in Volume Rendering



9. 3DVIEWNIX-AVS

This is a software package for the visualization and analysis of arteries and veins in contrast-enhanced MRA images.

Utilizes 3DVIEWNIX functions and the fuzzy connectedness technology.

Allows independent examination of arteries and veins.

Team: J.K. Udupa, T. Lei, P.K. Saha, D. Odhner, and L.G. Nyul.

10. <u>3DVIEWNIX-TV</u>

This is a software package for quantifying the various components of brain tumor via multiprotocol MR imagery.

Utilizes 3DVIEWNIX functions and fuzzy connectedness technology.

Currently being evaluated by the American College of Radiology Imagery Network.

Team: J.K. Udupa, J.G. Liu, and D. Odhner.