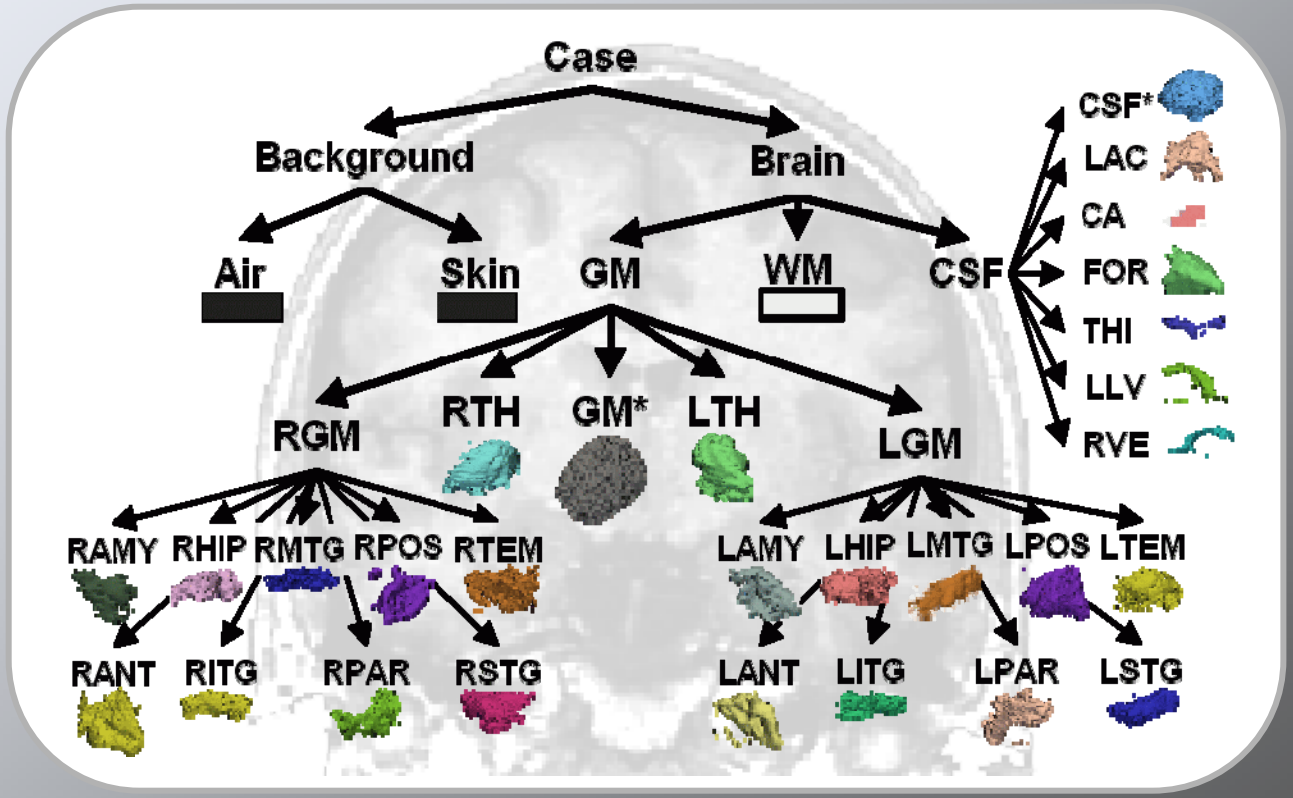
# Tools for Processing Medical Images

By
Kilian Maria Pohl




pohl@csail.mit.edu ♦ http://www.csail.mit.edu/~pohl

# Overview

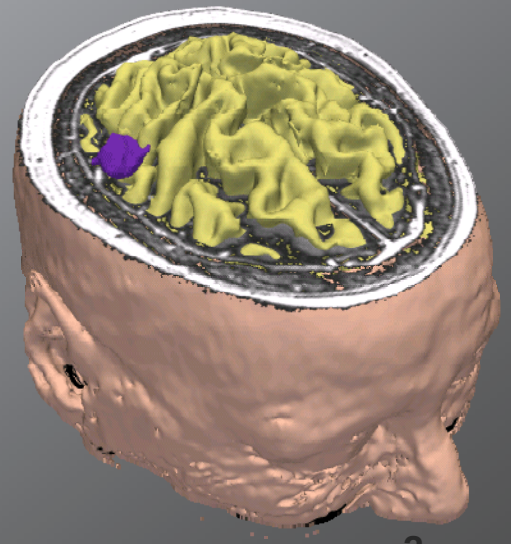
**Motivation**

**Software for Processing Images**

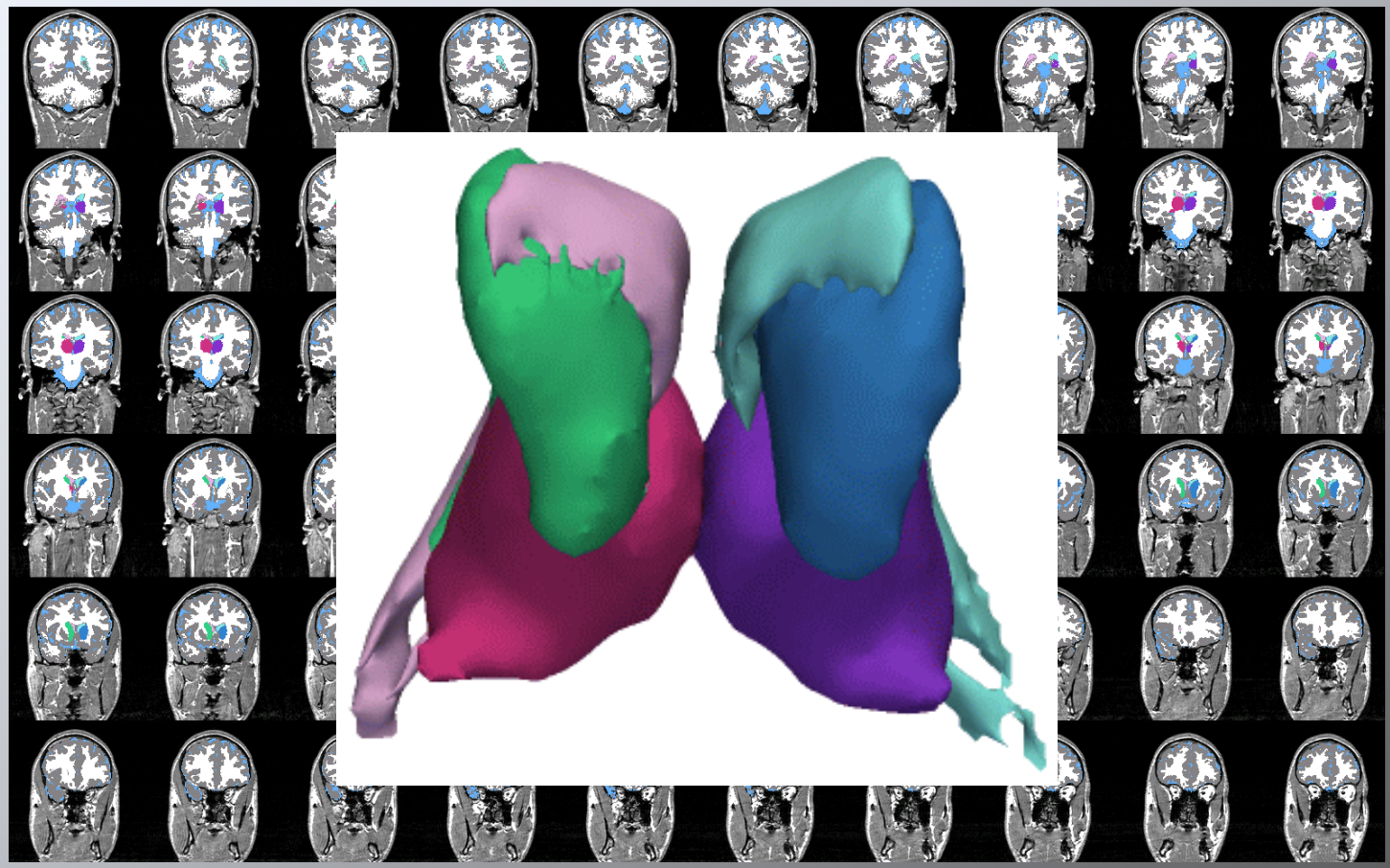
**Automatic Segmentation**

**Measuring Tumor Growth**

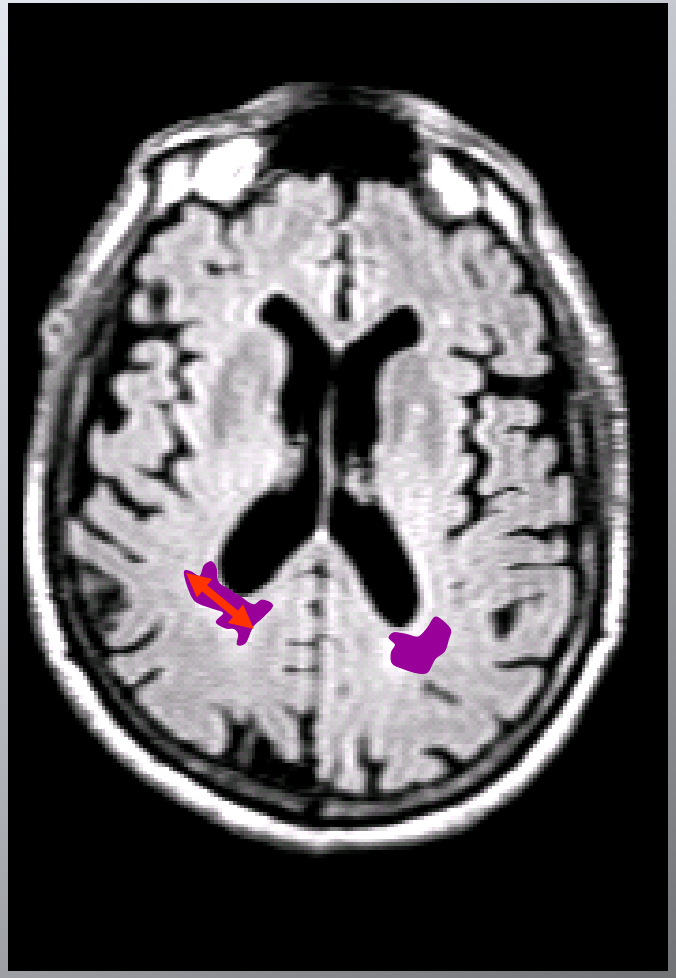
**Conclusion**



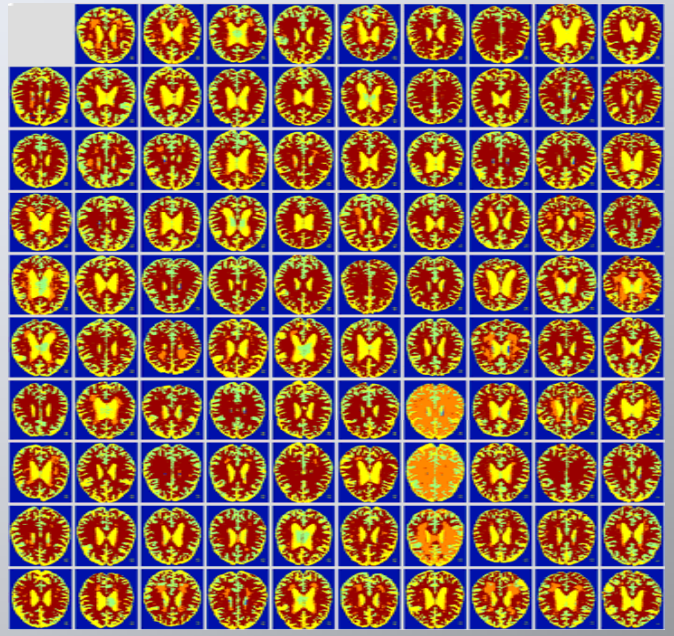
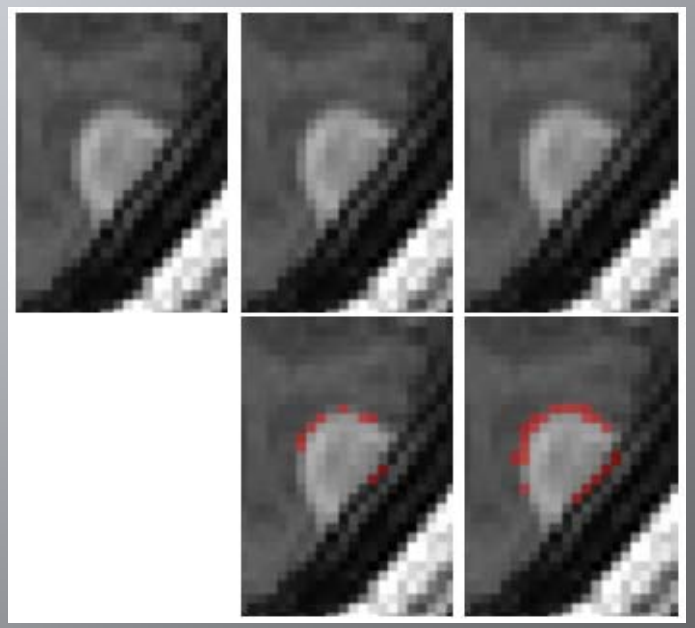
# Neuroscience Studies



# Multiple Sclerosis Lesion

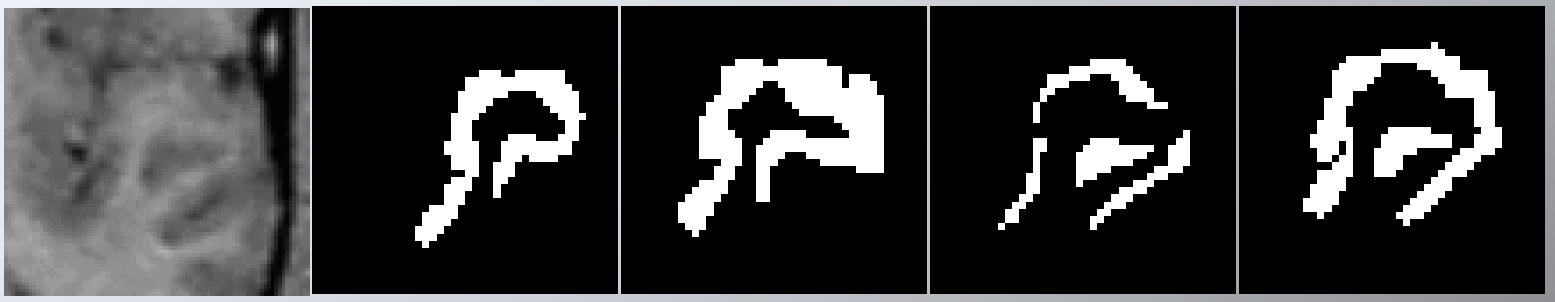


# Finding Differences

| Across Subjects | Within Subjects |
| --- | --- |
|  |  |

courtesy of Istvan Csapo

# Manual vs. Automatic



## Manual Segmentation:

- Very expensive
- High risks related to observer reliability

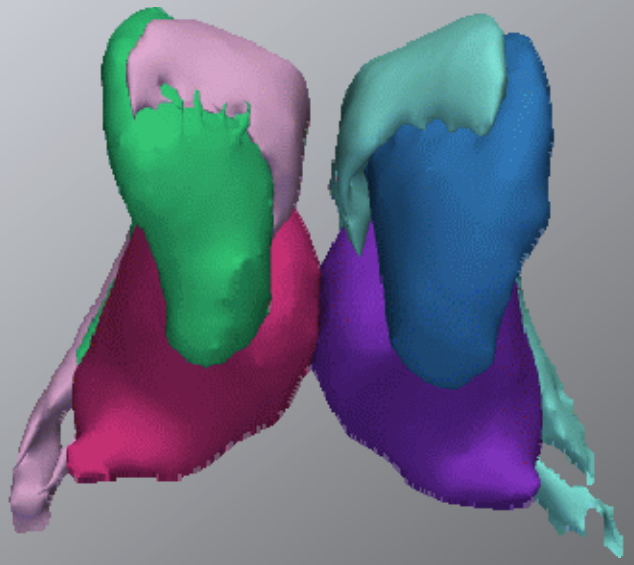
## Automatic segmentation:

- Relatively cheap
- Quality is often lower than manual segmentations

# Goal

Develop tools for processing medical images:

- fast and flexible
- requiring minimal amount of training effort
- include prior information



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# What is 3D Slicer?

- A platform for exploring novel image analysis and visualization techniques
- A freely-downloadable code and executables available for Windows, Linux,and Mac OS X

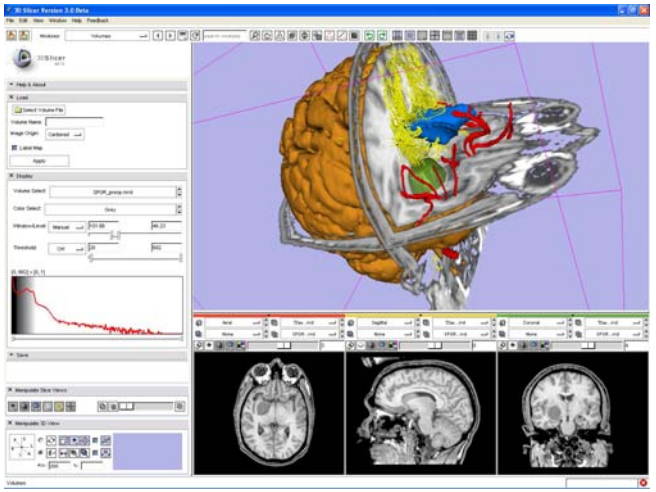


Image provided by S. Pieper

- Slicer is a research platform:
  - NOT FDA approved
  - NOT finished (work in progress)

# 3D Slicer

- www.slicer.org
- Over 500k lines of code
- 32 active developer
- Tutorial:
  Google: slicer 101

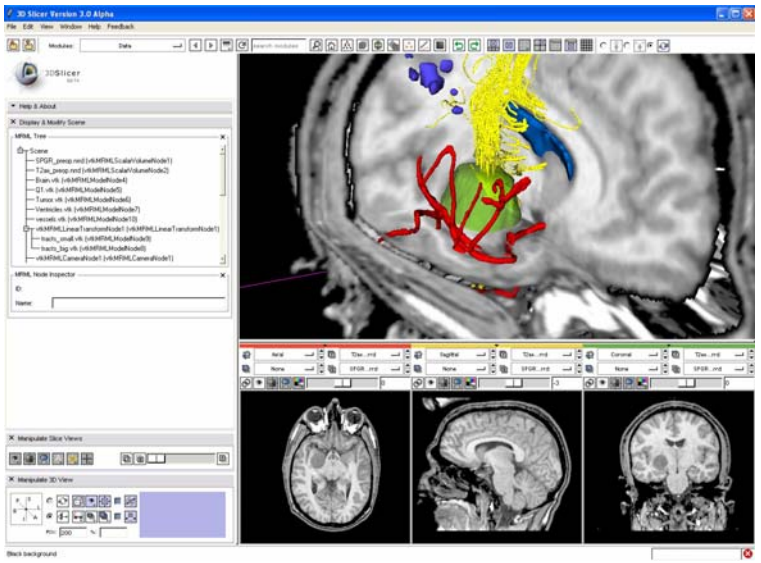
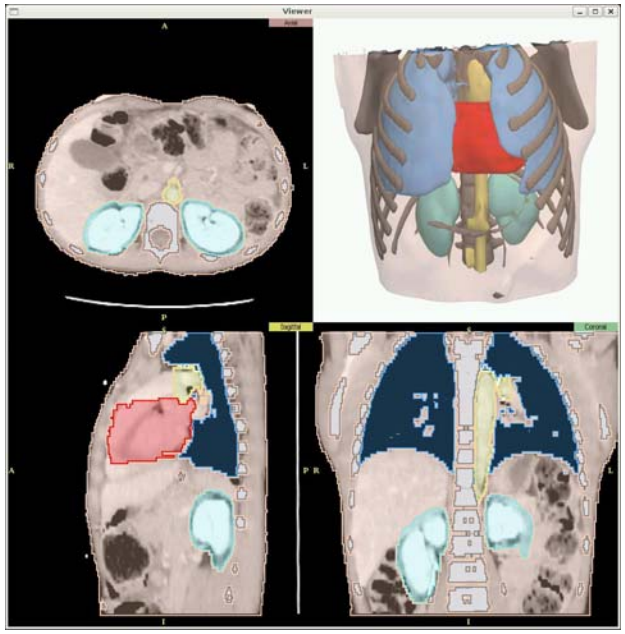


Image provided by A. Golby, F. Talos, P. Black

# Slicer Features

- Visualization
- Filtering
- Registration
- Segmentation
- DTI
- Quantification
- Real-time Integration



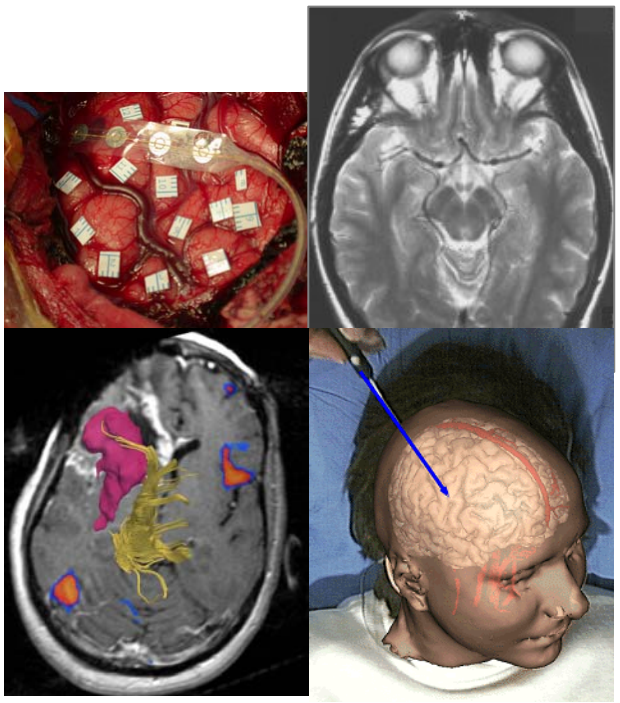
# Algorithms: DTI

- Automatic extraction of anatomically meaningful fiber bundles
- Advanced Rendering methods for segmentation results using photon mapping

Rendering provided by Banks, Data by Odonnell, Shenton, Westin, et al.

# Image Guided Therapy (IGT)

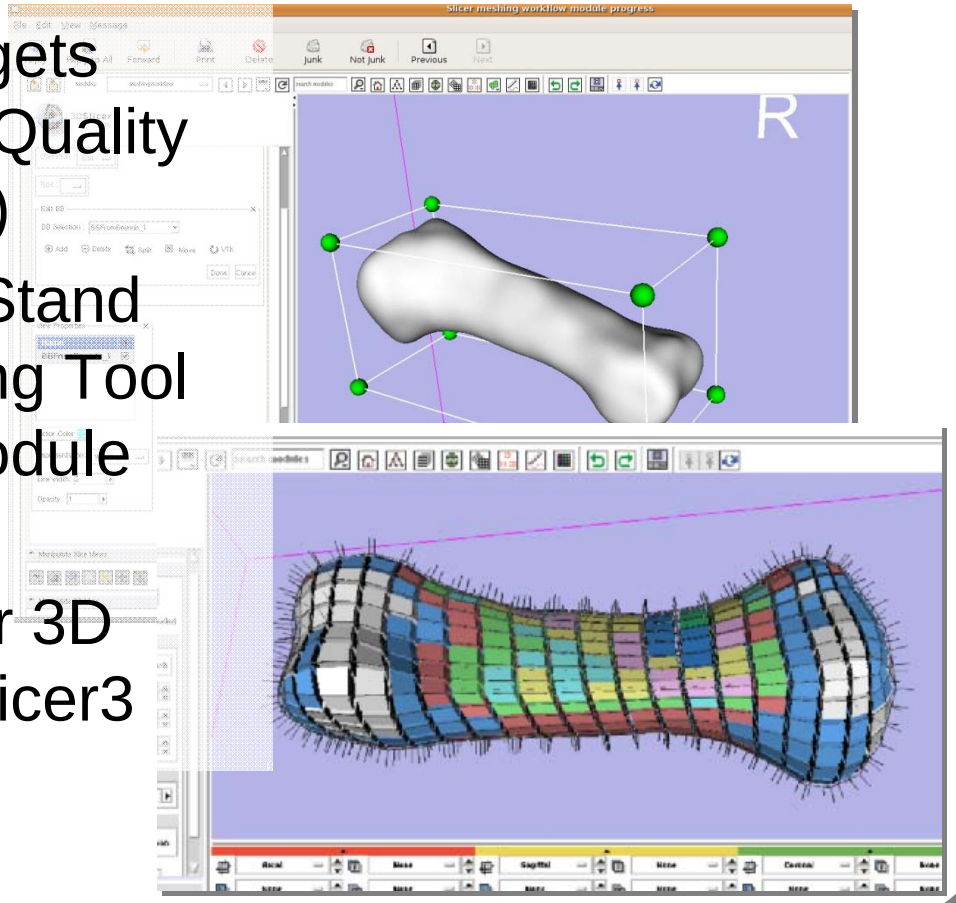
- Active visualization of medical images to aid in decision making.
- Allows physician to
  - See Beyond the Surface
  - Define Targets
  - Control the Interventions
- Enables new procedures, decreases invasiveness, optimizes resection



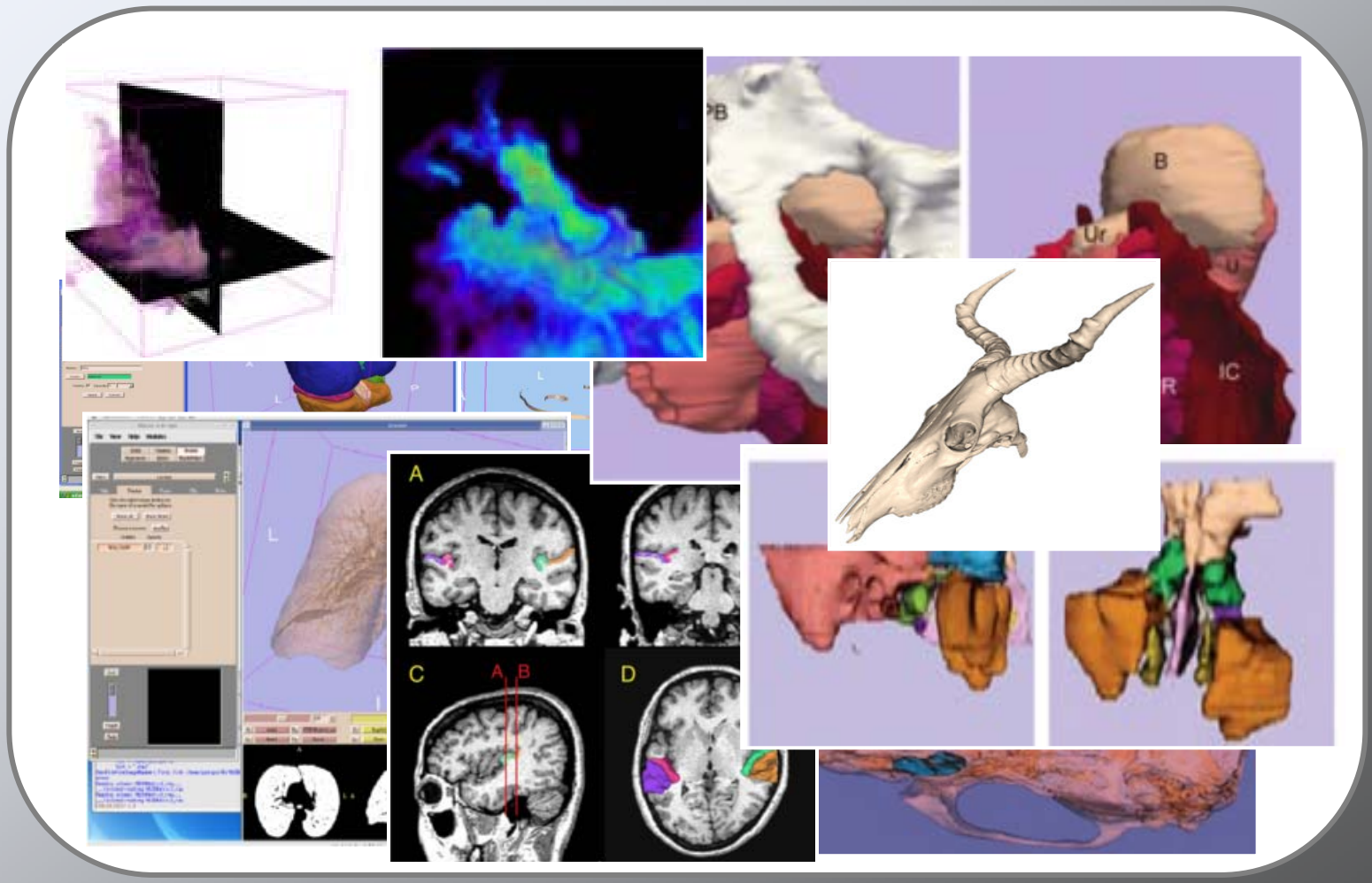
Dimaio SP, Archip N, Hata N, Talos IF, Warfield SK, Majumdar A, Mcdannold N, Hynynen K, Morrison PR, Wells WM 3rd, Kacher DF, Ellis RE, Golby AJ, Black PM, Jolesz FA, Kikinis R.: Image-guided neurosurgery at Brigham and Women's Hospital.IEEE Eng Med Biol Mag. 2006 Sep-Oct;25(5):67-73

# U Iowa Meshing Project

- VTK/KWWidgets based Mesh Quality Viewer (Lisle)
- Migration of Stand Alone Meshing Tool into Slicer Module (Lisle)
- Key Driver for 3D Widgets in Slicer3



# Many More Examples



# NA-MIC Kit Components

- End User Application
  - –3D Slicer
- Image Analysis, Visualization, and GUI libraries
  - –ITK, VTK, KWWidgets
- Large Scale Data Processing Tools
  - –Batchmake, BIRN GRID tools
- Software Engineering Tools
  - –CMake, Dart, CTest, CPack

http://www.na-mic.org/Wiki/index.php/SoftwareInventory






# Acknowledgments

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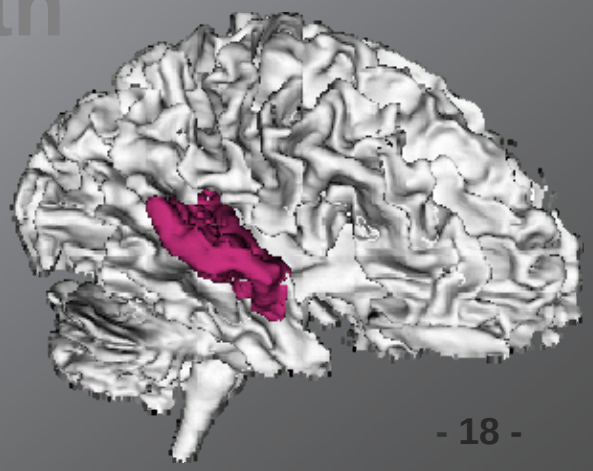


# Tissue Classification

Software:

-EM

Wells 96

-EMS

Van Leemput 99

-SPM

Ashburner 03

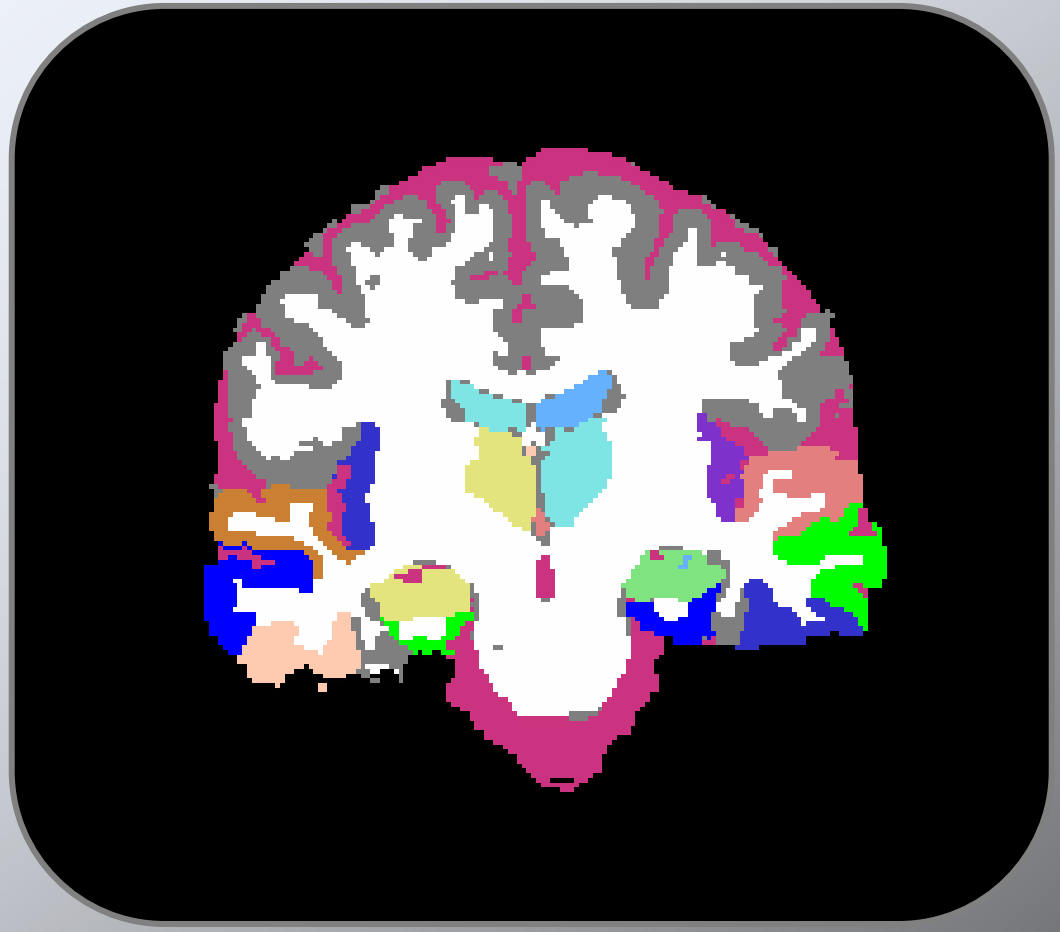
-MNI

Zijdenbos 02

-FSL

Zhang 01

# Cortical + Subcortical Parcellation



## Software:

-ANIMAL
Collins 99

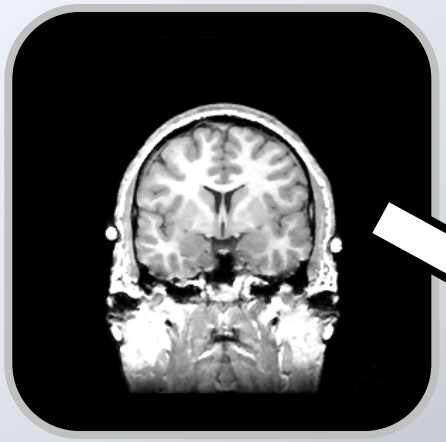
-EM-MF-LP
Pohl 02

-Freesurfer
Fischl 02

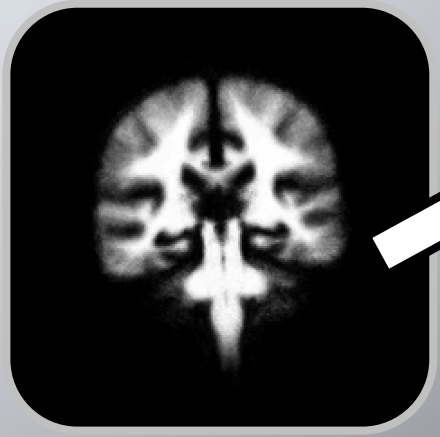
-BrainSuite
Thompson 04

-FANTASM
Tosun 04

# Mission

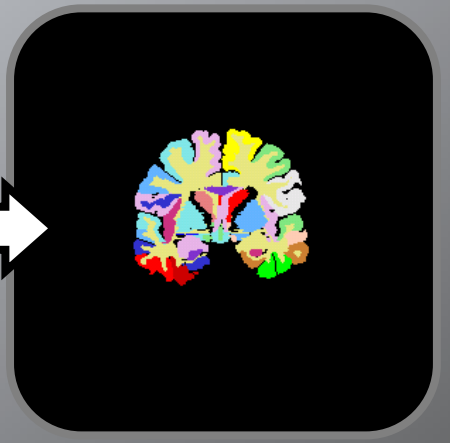


MRI



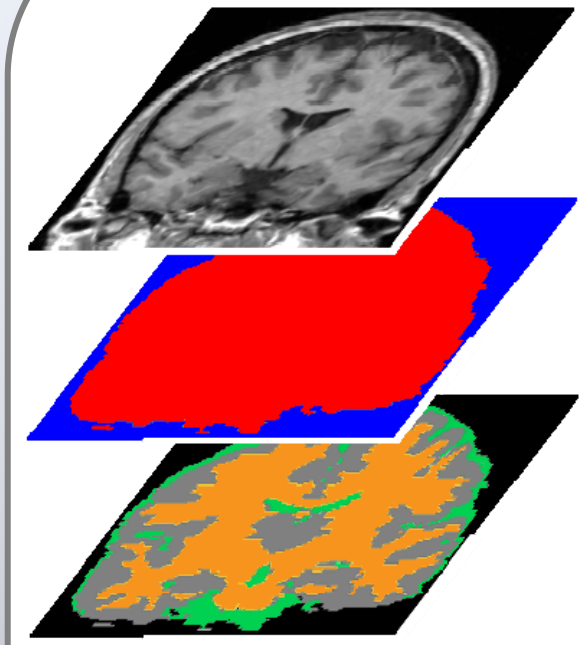
Atlas

**Tool**



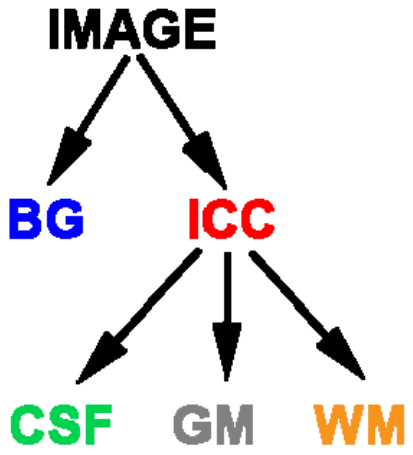
Label Map

# Hierarchical Tree

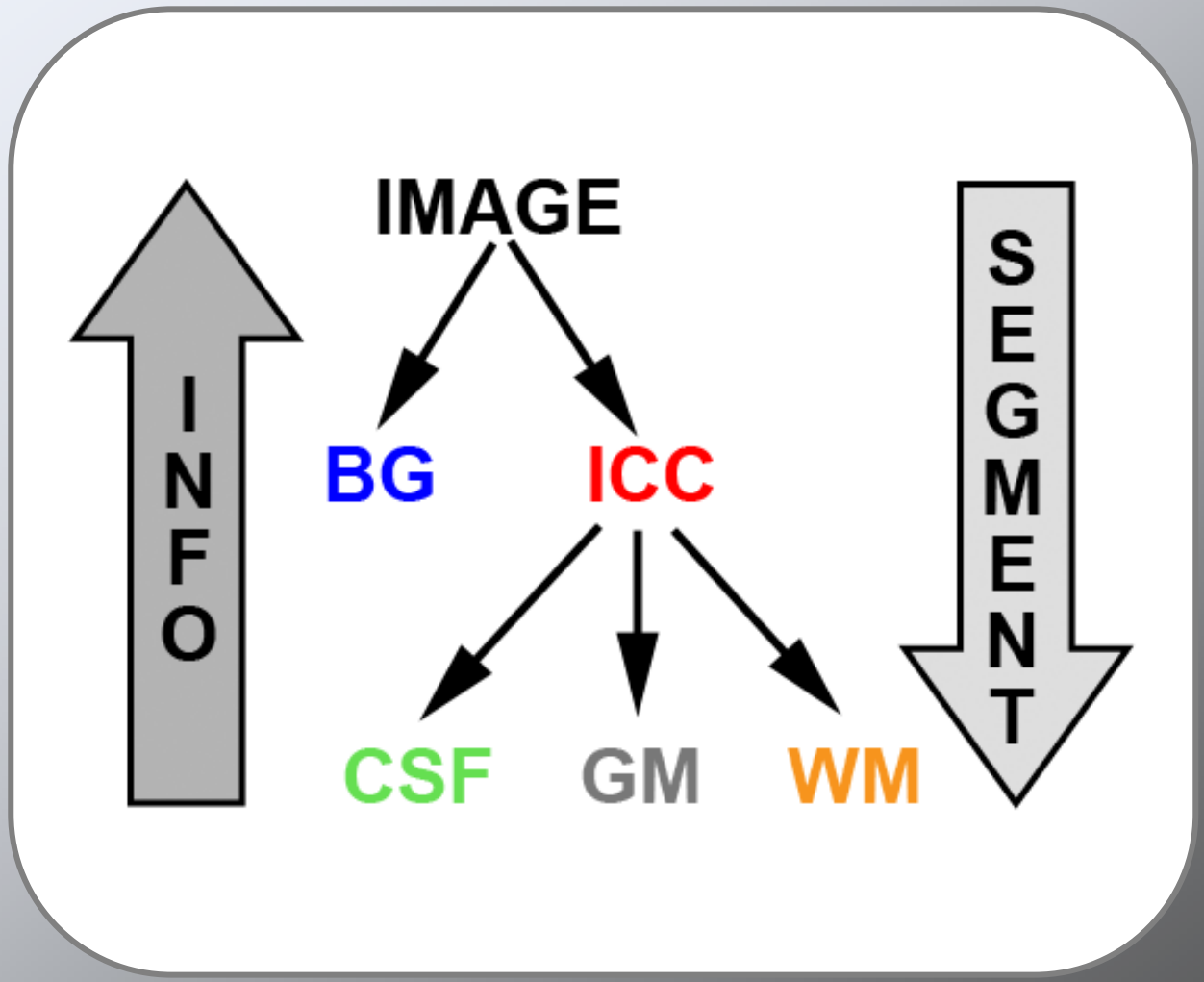


Find Cranial Cavity:

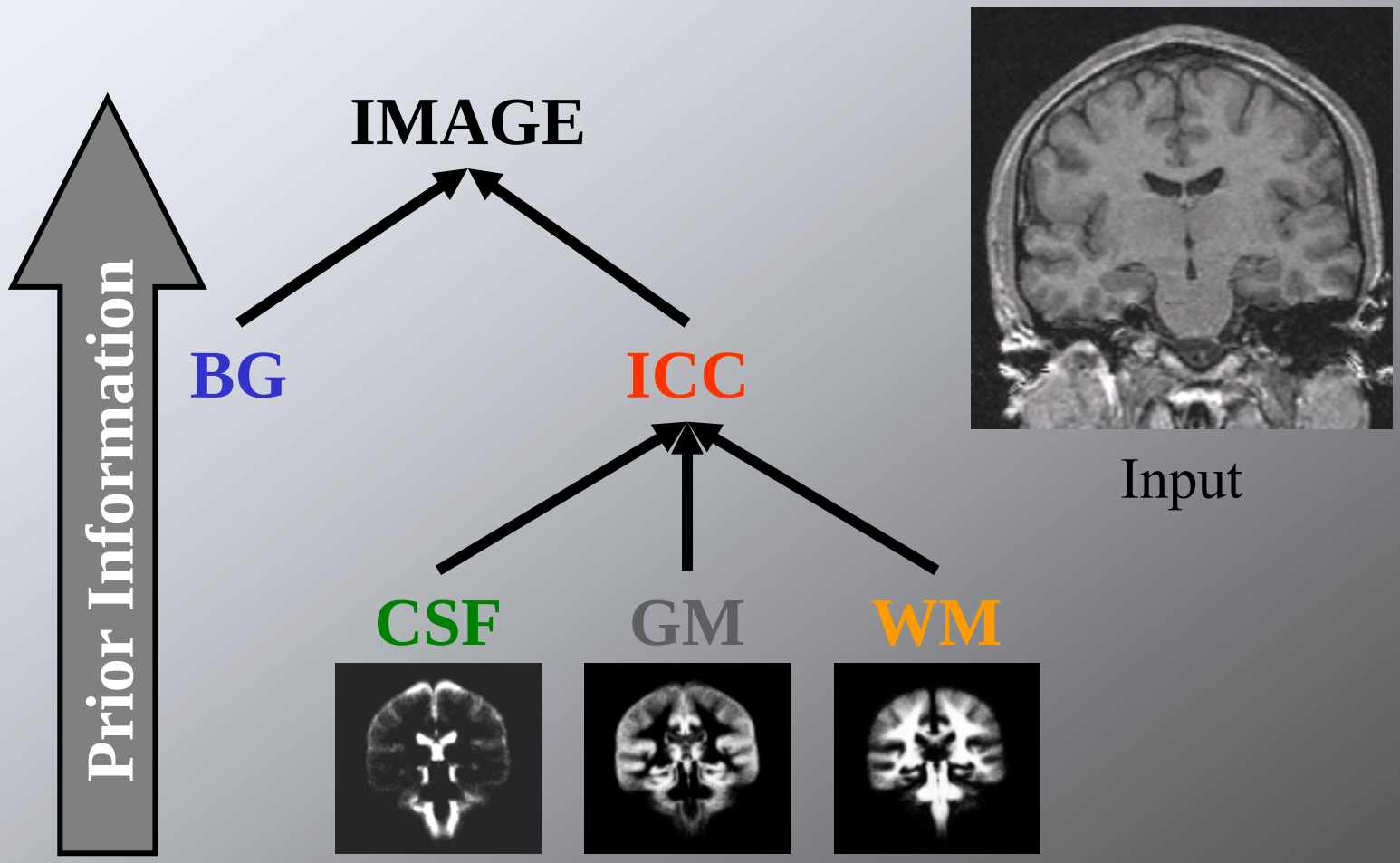
Find Tissue:



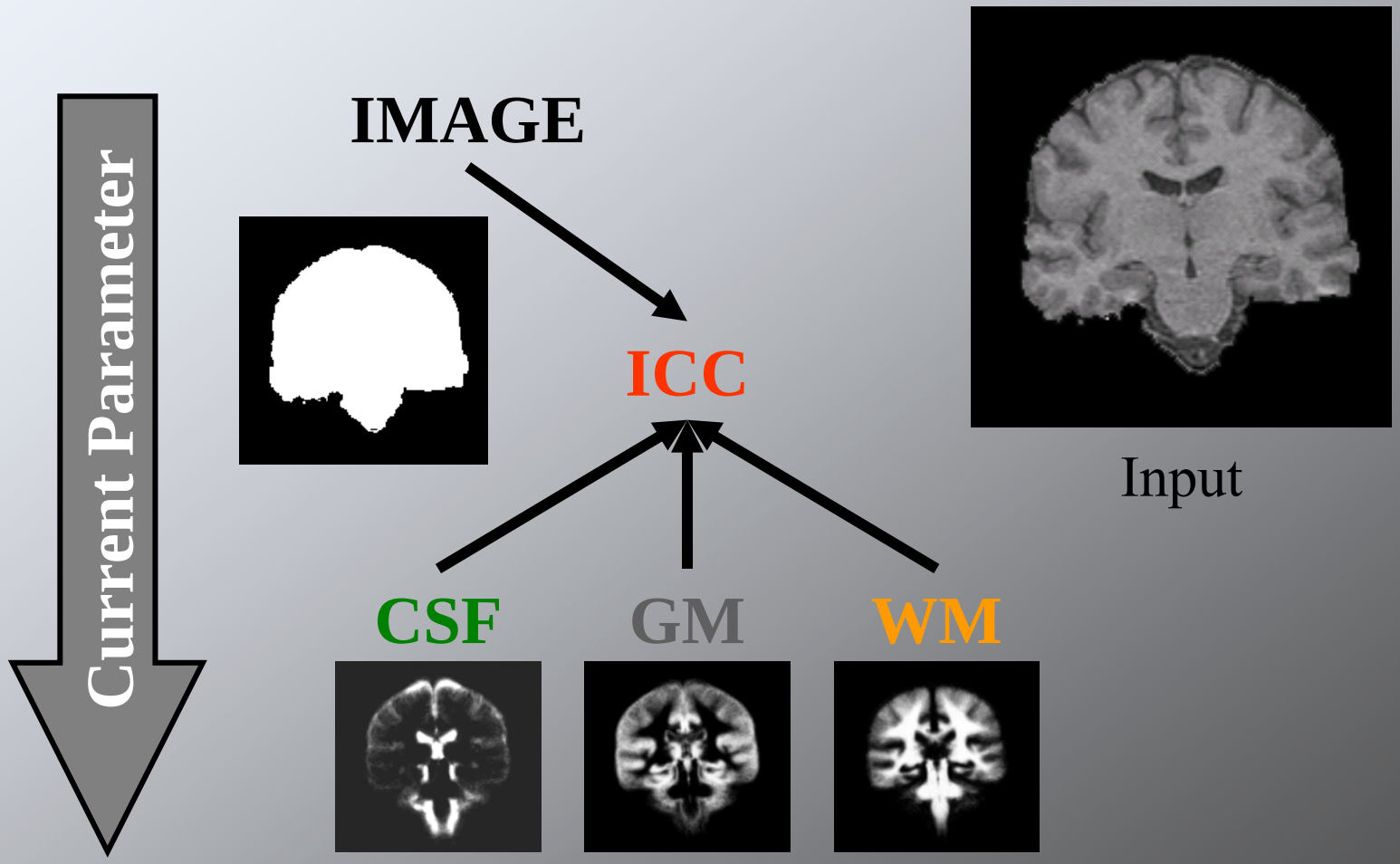
# Design of Algorithm



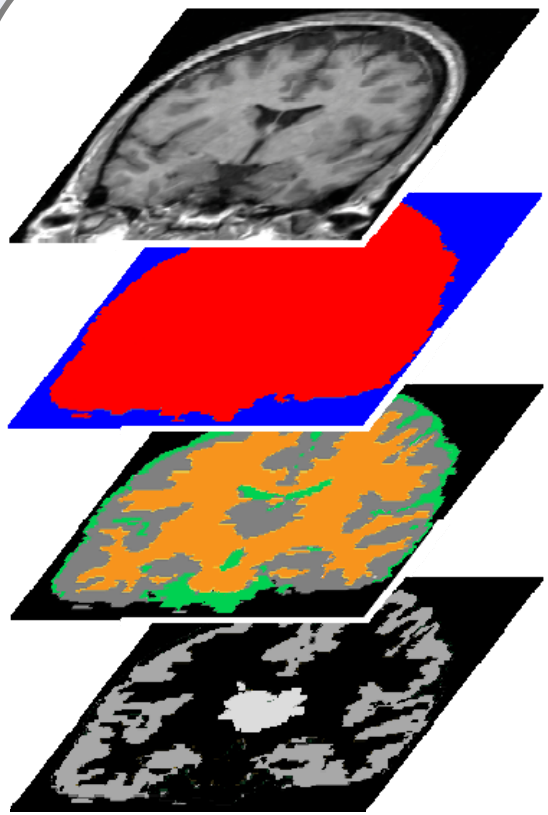
# Level 1



# Level 2



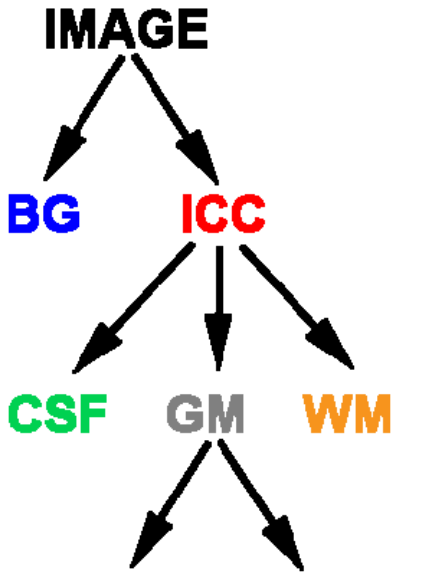
# Modify the Tree



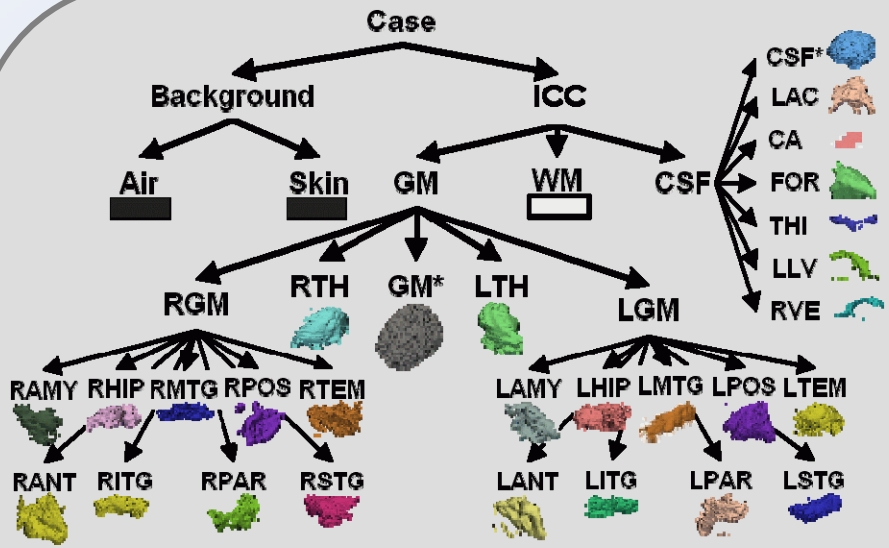
Find Cranial Cavity:

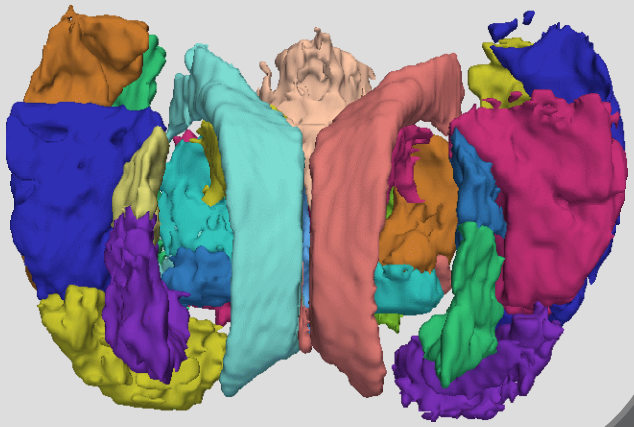
Find Tissue:

Find Substructures:



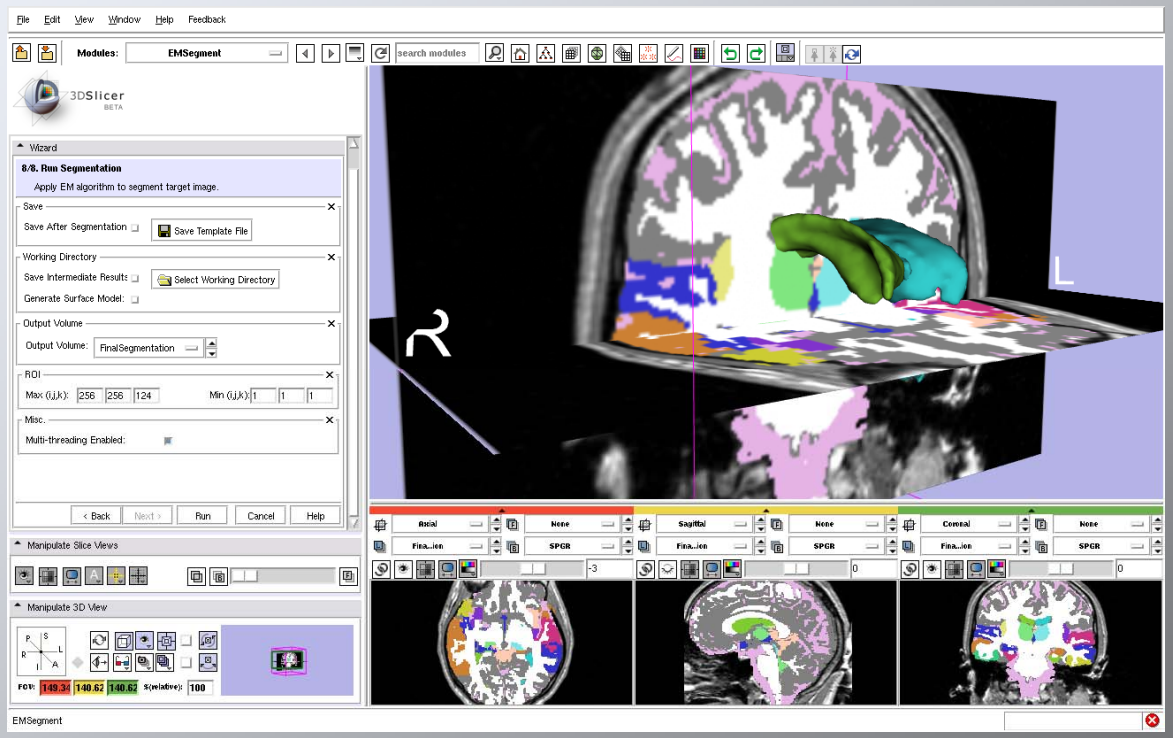
# Segmentation of 31 Structures



Pohl et al., ISBI 04

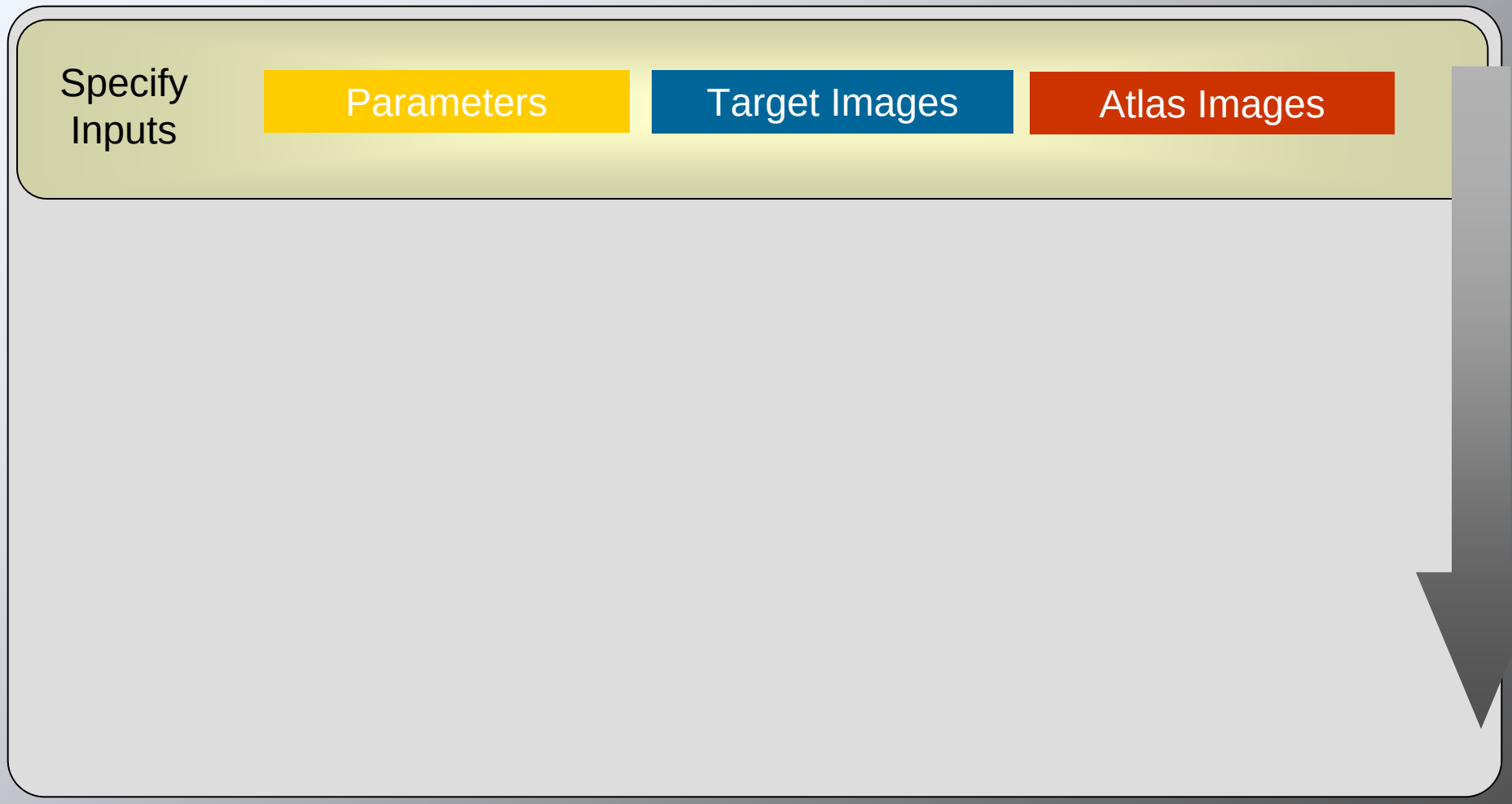
# Software in 3D Slicer




Download: www.slicer.org
Tutorial: http://wiki.na-mic.org/Wiki/index.php/Slicer:Workshops:User_Training_101

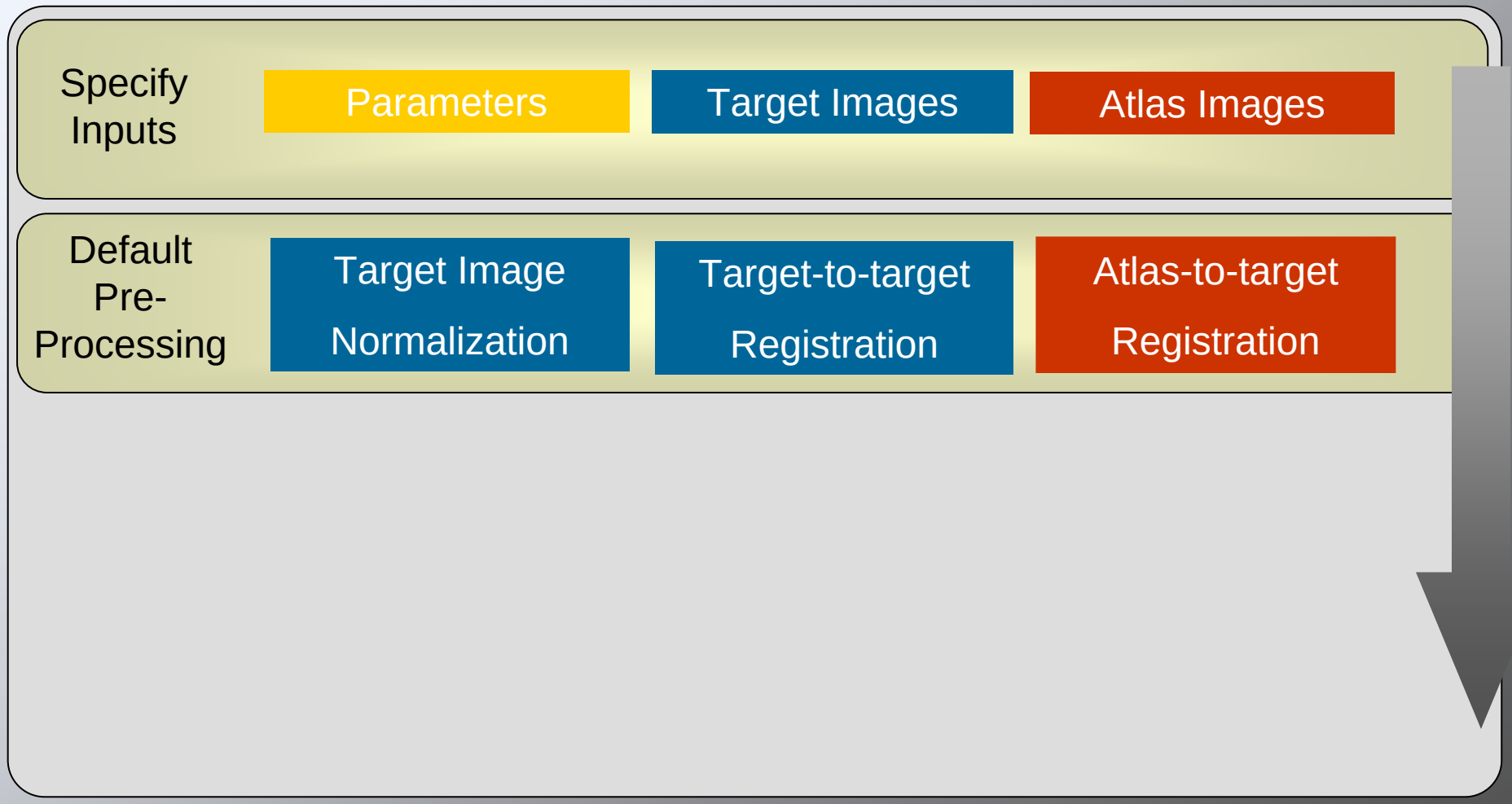
S. Bouix et al. On evaluating brain tissue classifiers without a ground truth, NeuroImage, Volume 36, Issue 4, pp 1207-1224, 2007

# EM Segment Workflow




courtesy of Brad Davis

# EM Segment Workflow




courtesy of Brad Davis

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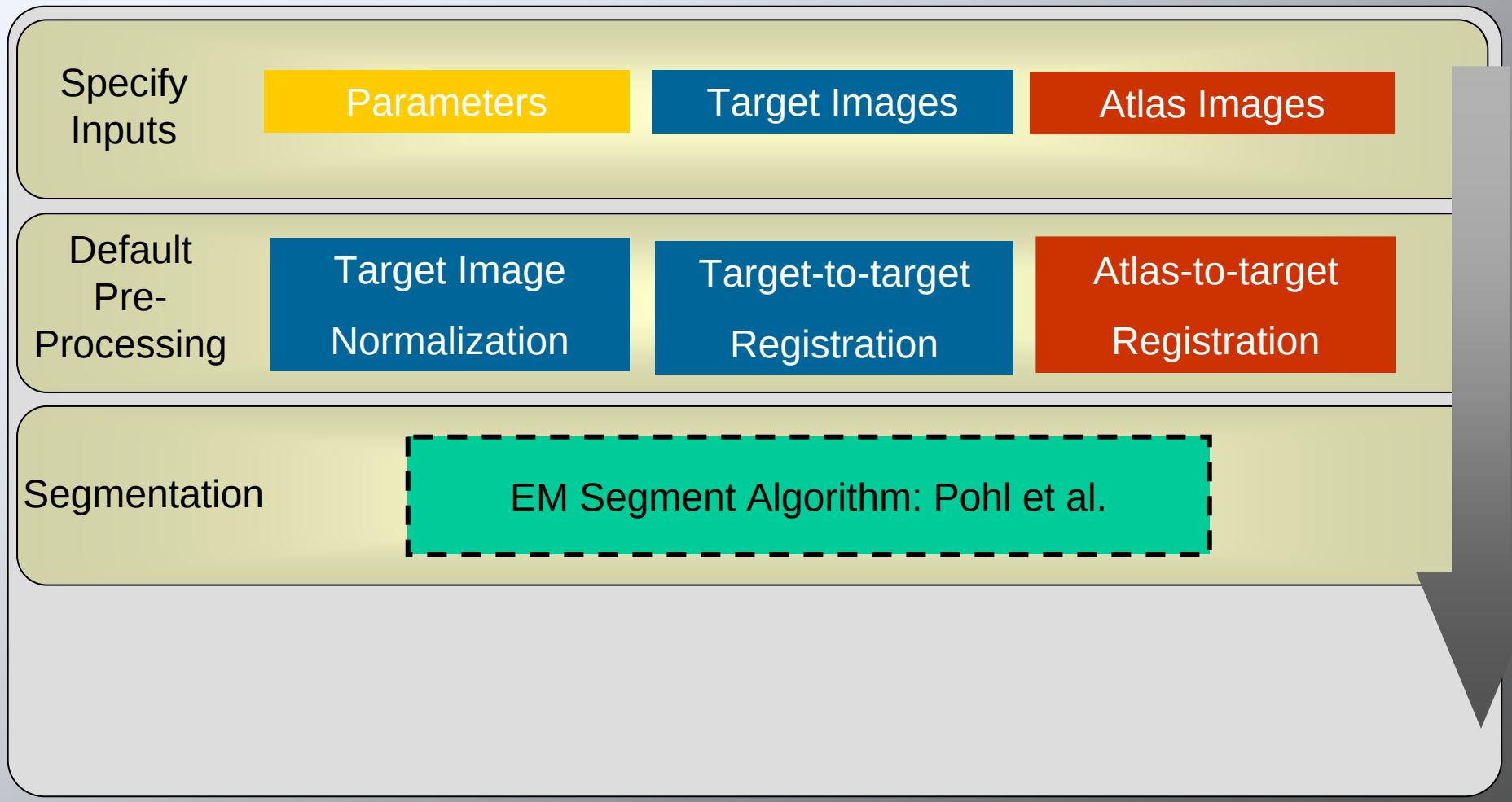


courtesy of Brad Davis

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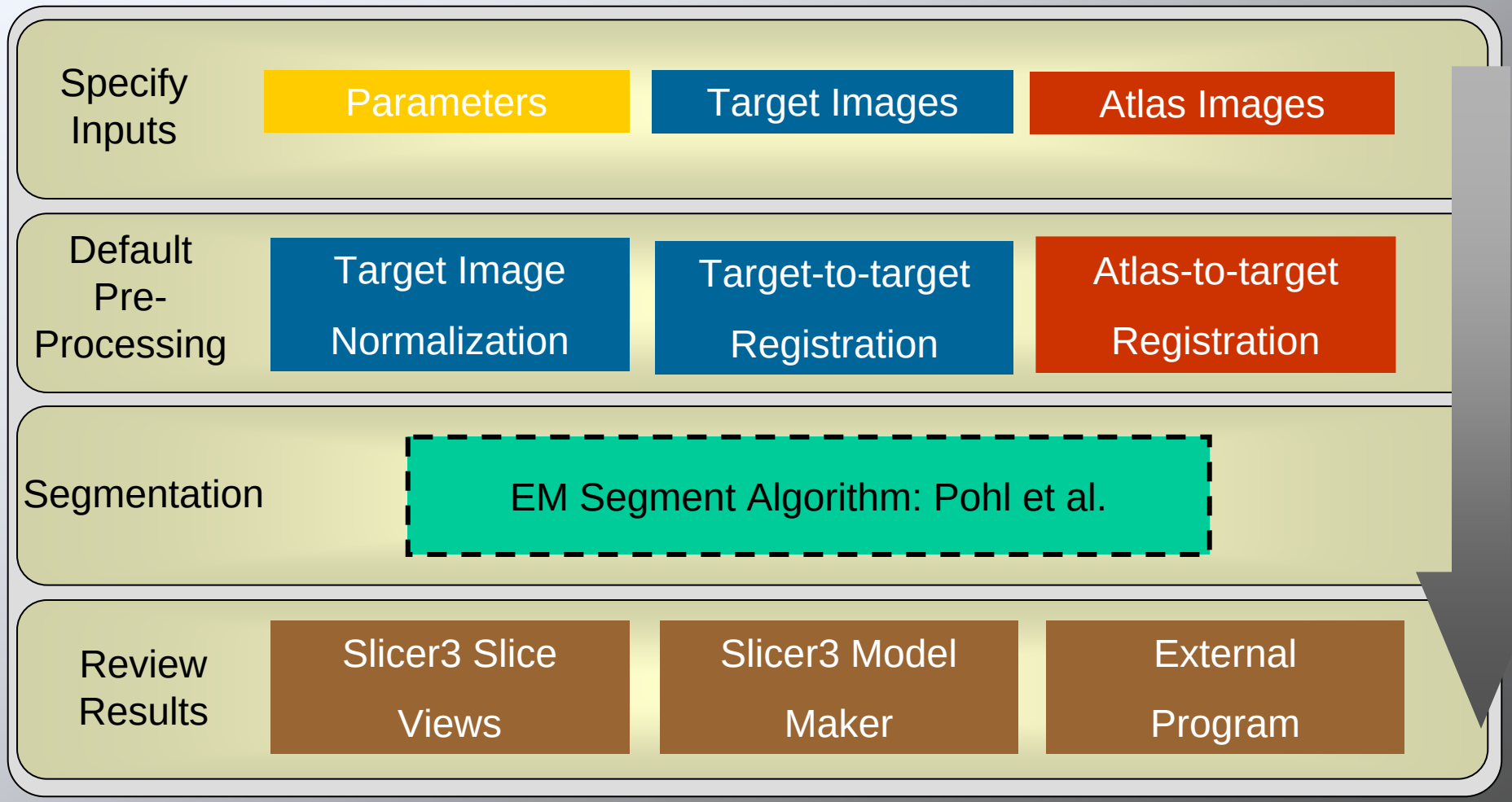


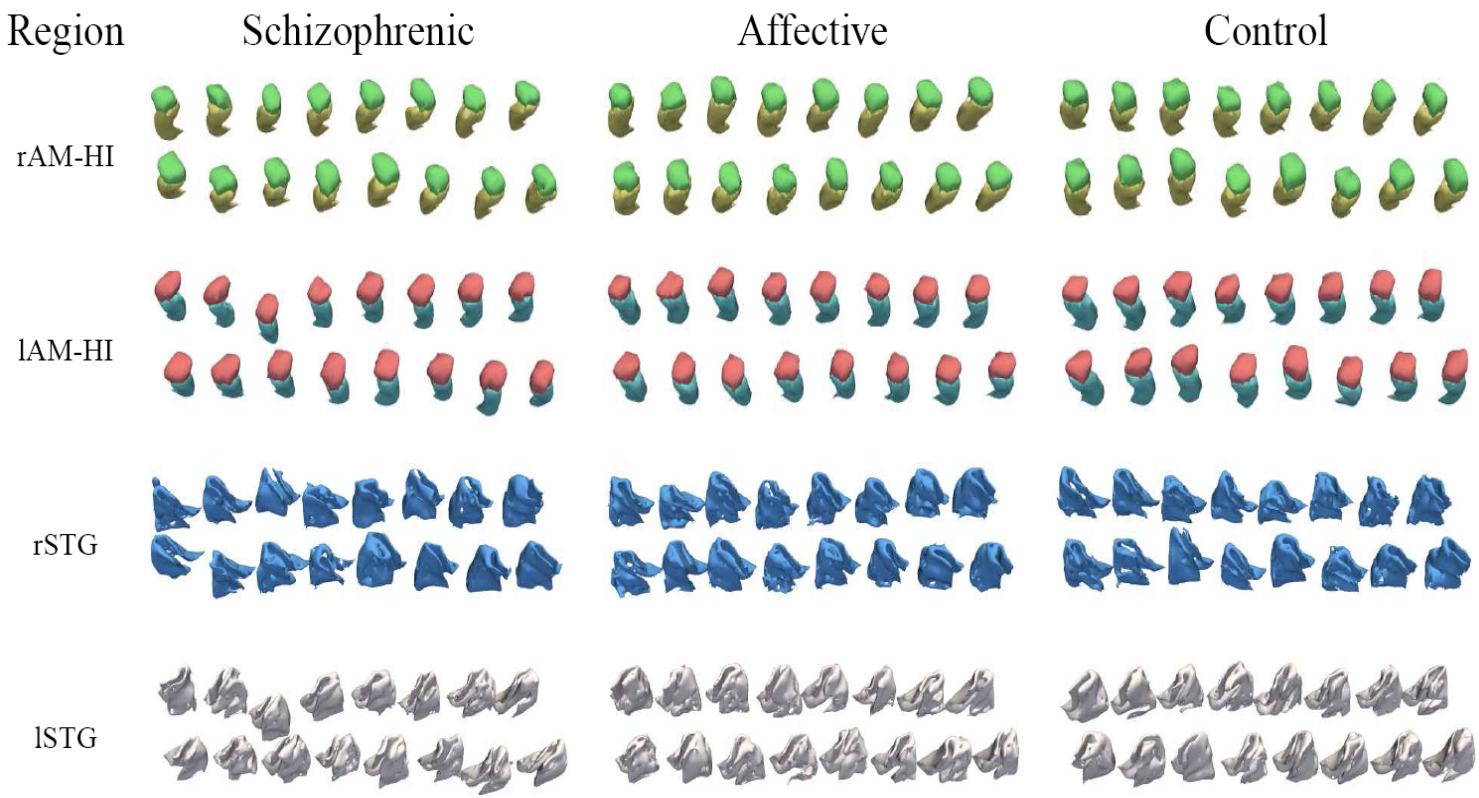

courtesy of Brad Davis

# Dissemination

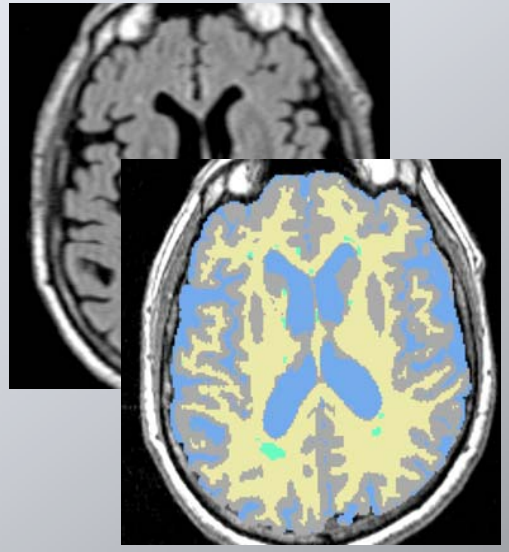
- Integration into Slicer 3
  http://wiki.na-mic.org/Wiki/index.php/Slicer3:EM
- Grid Computing
- Tutorial
  http://wiki.na-mic.org/Wiki/index.php/
  Slicer:Workshops:User_Training_101

*NA-MIC*
*National Alliance for Medical Image Computing*
*http://na-mic.org*

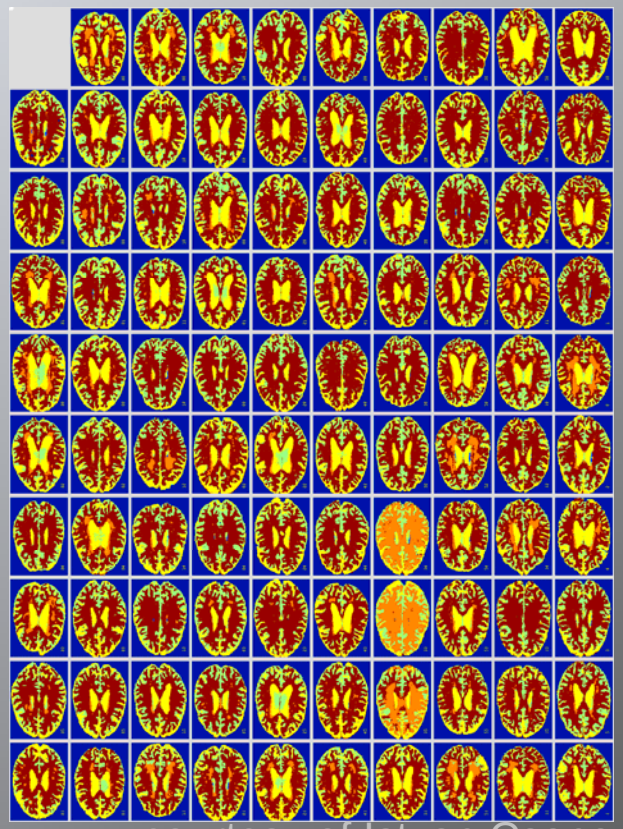
# Morphometry Study TMI '07



# Lesion Detection



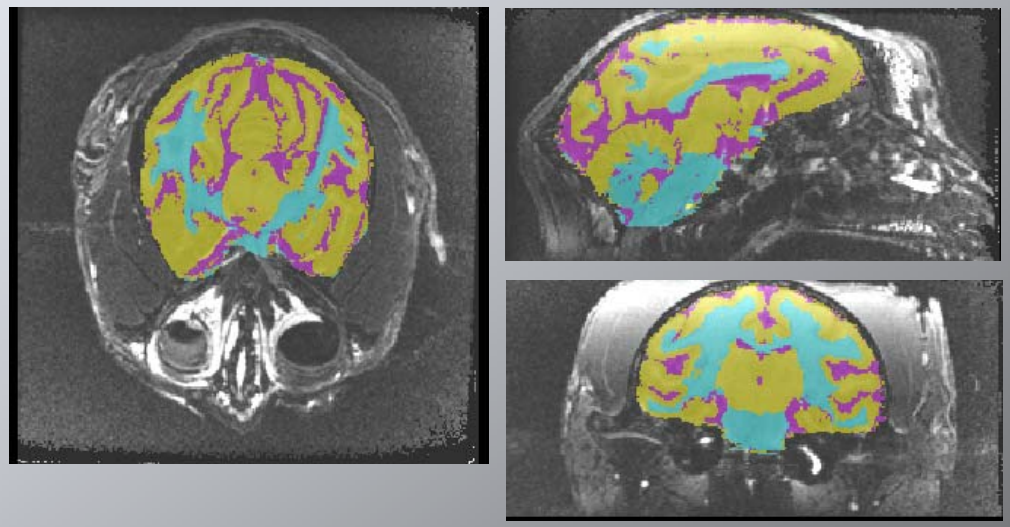
Progression of Multiple Sclerosis lesions



courtesy of Istvan Csapo

# Non-Human Primates

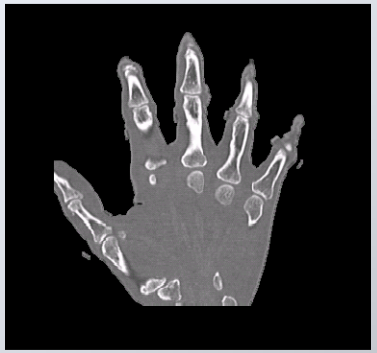
VIRGINIA TECH WAKE FOREST UNIVERSITY
School of Biomedical Engineering and Sciences



courtesy of Chris Wyatt

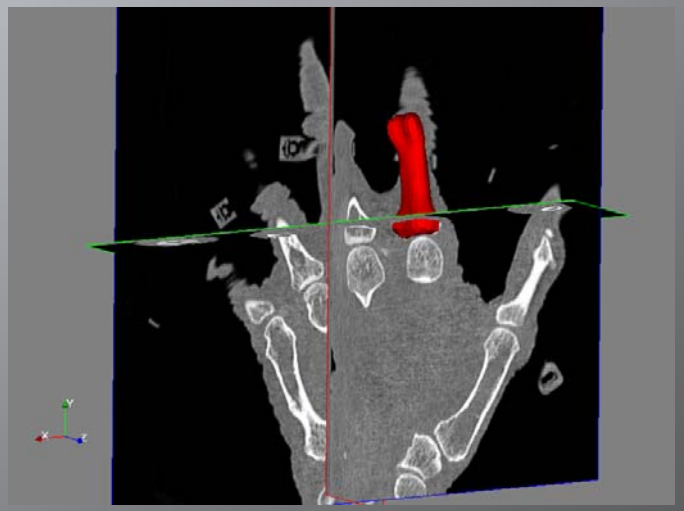
Measuring Alcohol and Stress Interactions with Structural and Perfusion MRI

# CT Hand Bone Segmentation



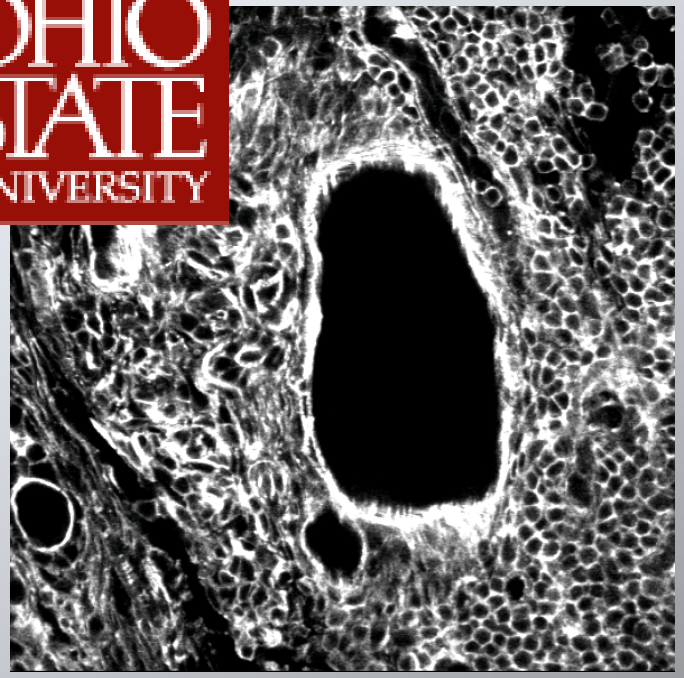
MIMX
THE UNIVERSITY OF IOWA

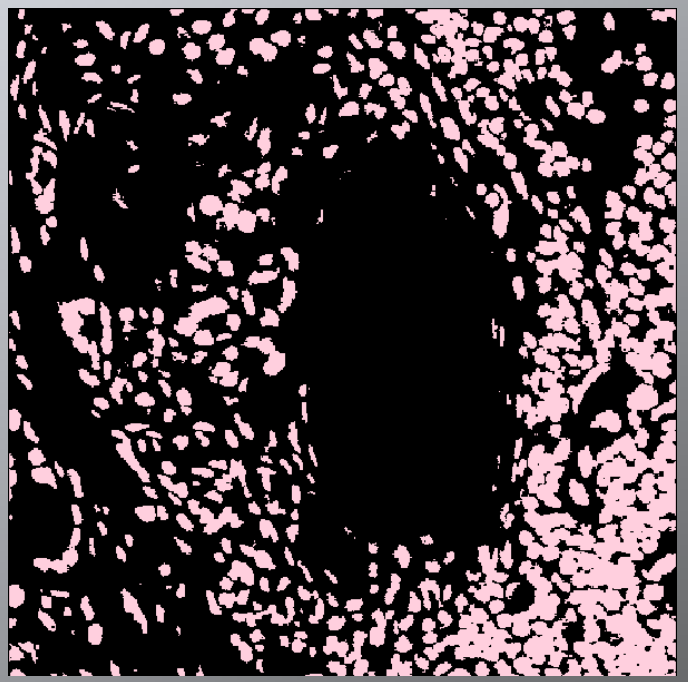
Developing patient-specific kinematic models



courtesy of Austin Ramme and Vince Magnotta

# Segmentation of Microscopy Images





courtesy of Brad Davis

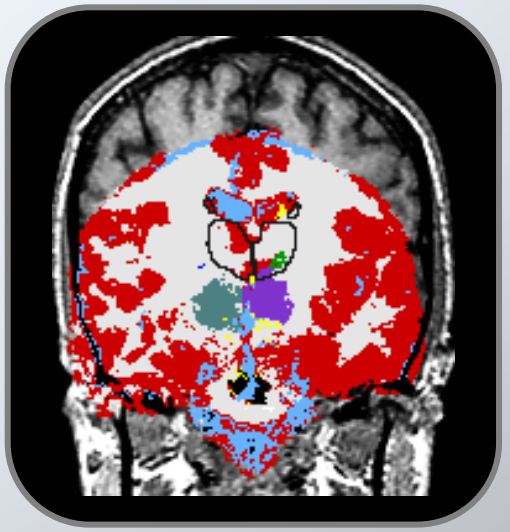
Detecting patterns in biology

# Publications


- Pohl et al. A hierarchical algorithm for MR brain image parcellation. IEEE Transactions on Medical Imaging, 26(9), pp 1201-1212, 2007.
- Nakamura et al. Neocortical gray matter volume in first episode schizophrenia and first episode affective psychosis: a cross-sectional and longitudinal MRI study. Biological Psychiatry, 2007. In Press.
- Koo et al. Smaller neocortical gray matter and larger sulcal CSF volumes in neuroleptic-naive females with schizotypal personality disorder. Archives of General Psychiatry, 63, pp. 1090-1100, 2006.
- Zöllei et al. The Impact of Atlas Formation Methods on Atlas-Guided Brain Segmentation, MICCAI 2007
- Pohl et al.  Anatomical Guided Segmentation with Non-Stationary Tissue Class Distributions in an Expectation-Maximization Framework, In Proc. ISBI'2004, pp. 81 – 84, 2004.


Papers are accessible through www.csail.mit.edu/~pohl

# Alternative Prior Model



## Simultaneous Registration and Segmentation

Pohl et al. A Bayesian Model for Joint Segmentation and Registration. NeuroImage, 31(1), pp. 228-239, 2006

## Shape Based Segmentation

Pohl et al., “Using the Logarithm of Odds to Define a Vector Space on Probabilistic Atlases", Medical Image Analysis, 2007 MedIA –MICCCAI Best Paper Prize 2006

Pohl et al. Active mean fields: Solving the mean field approximation in the level set framework.IPMI, vol. 4584 of LNCS, pp. 26-37, 2007.

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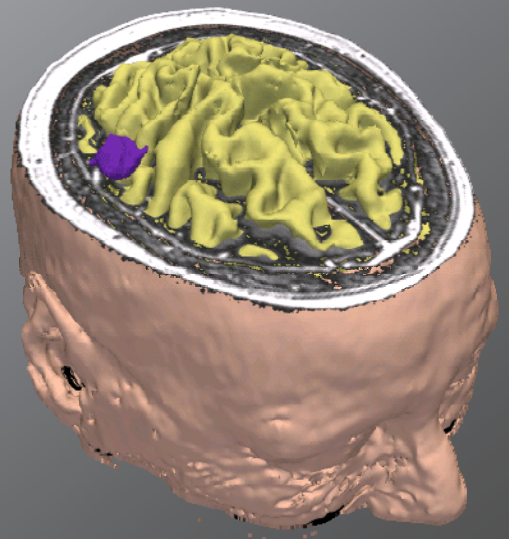
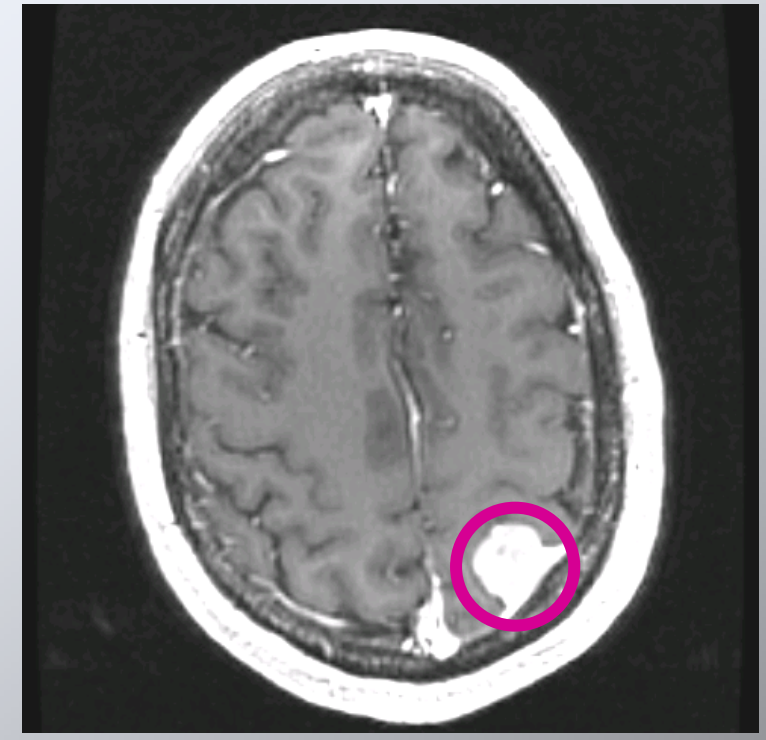
**Measuring Tumor Growth**

**Conclusion**

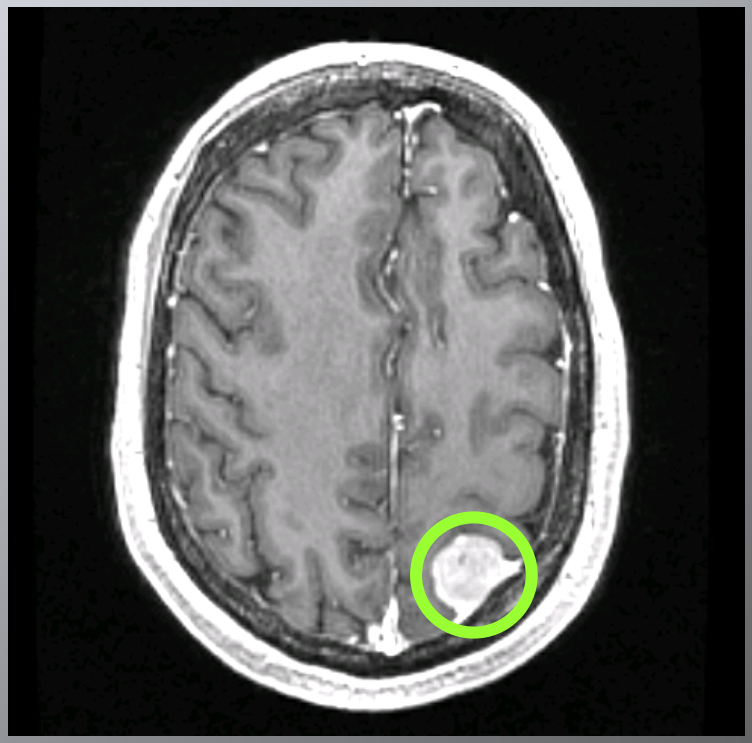


# Meningioma Patient

1st Scan



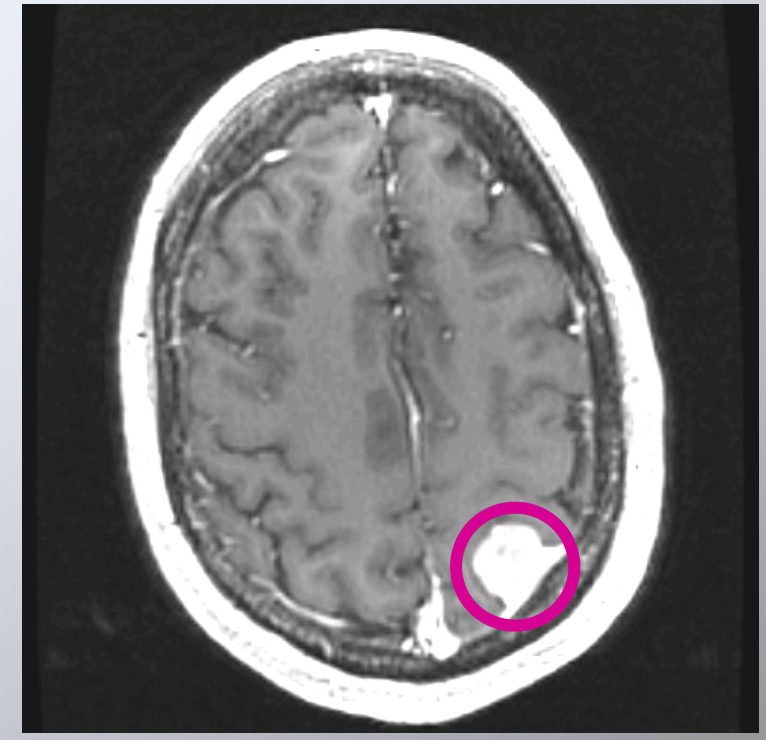
2nd Scan



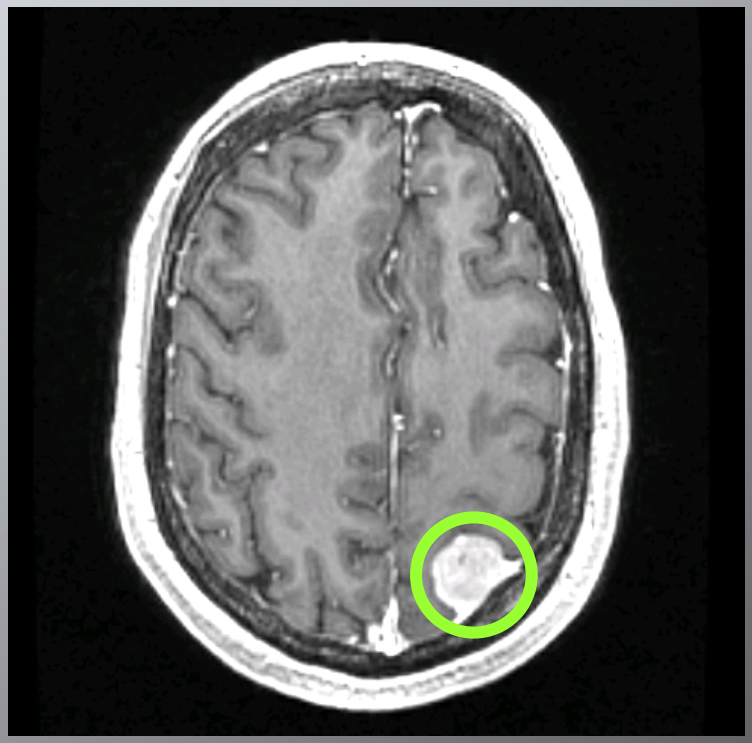
Monitor evolution of meningioma through periodic MR scanning of patient

# The Problem

1st Scan



2nd Scan



Has this tumor changed? Bigger? Smaller?

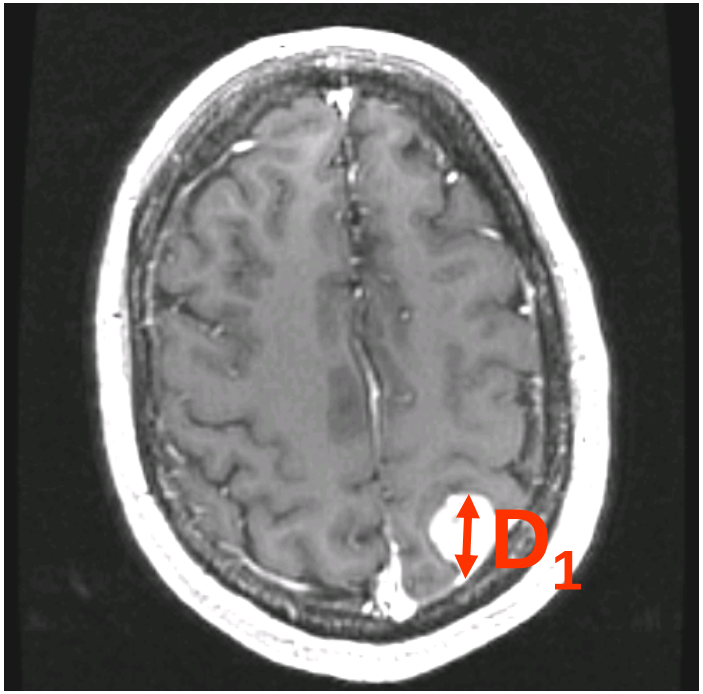
# Accuracy of Manual Inspection

| real MRI | 1% (10mm$^3$) | 5% (48mm$^3$) | 22% (195mm$^3$) |
|---|---|---|---|
|  |  |  |  |
| Expert | 0/5 | 1/5 | 5/5 |

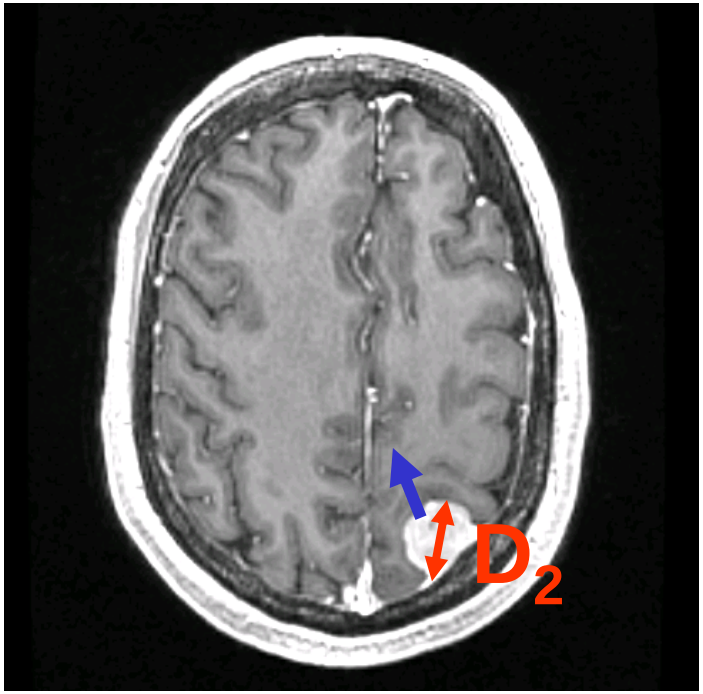
Konukoglu et al. ,“Monitoring Slowly Evolving Tumors”, ISBI 08

# RECIST

1st Scan




2nd Scan

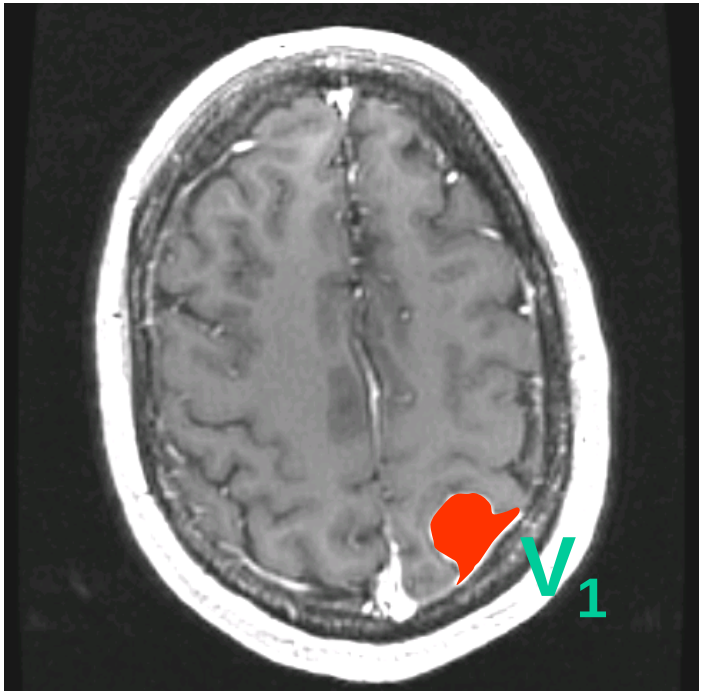



**Infer change from largest diameter**

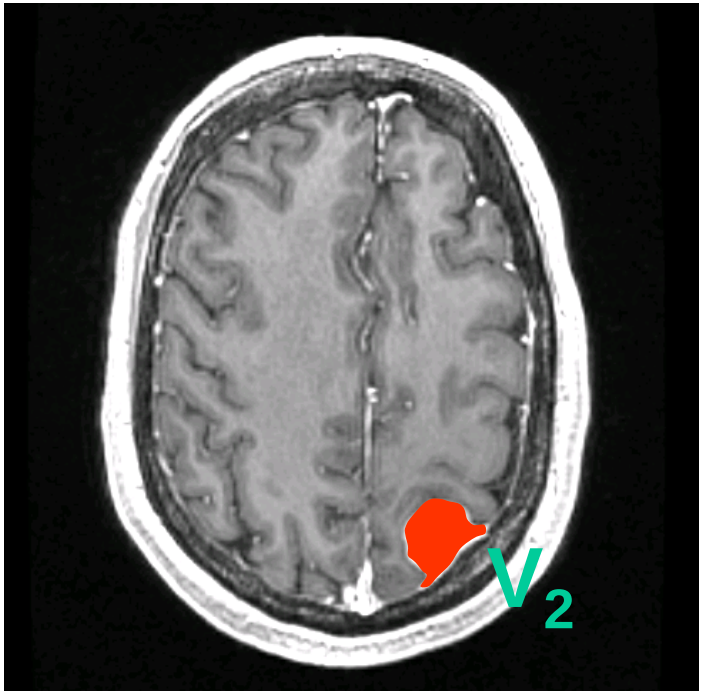
**$D_1 >> D_2$ or $D_1 << D_2$**

# Manually Determine Volume

1st Scan




2nd Scan

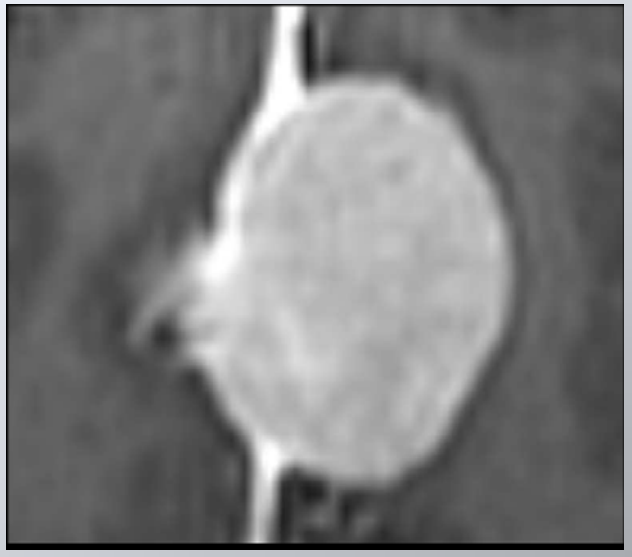



**Infer Change from Largest Volume**

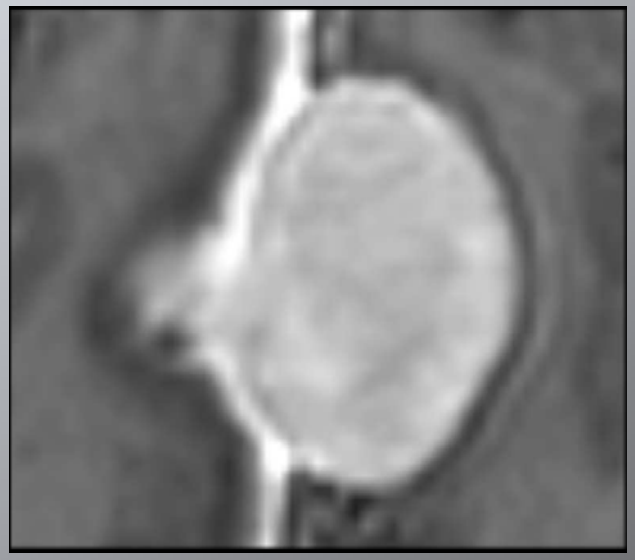
**$V_1 >> V_2$ or $V_1 << V_2$**

# Intra-Rater Reliability

Scan 1



Scan 2

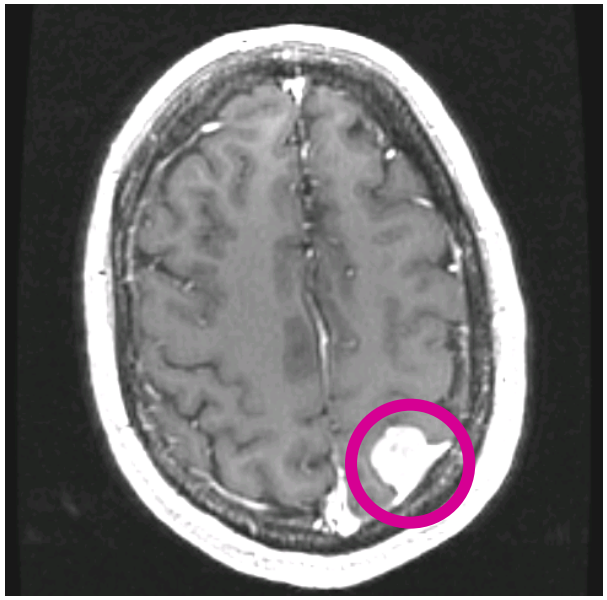


| First | Second | Third |
|---|---|---|
| 883.8 $mm^3$ | 545.8 $mm^3$ | −99.8 $mm^3$ |

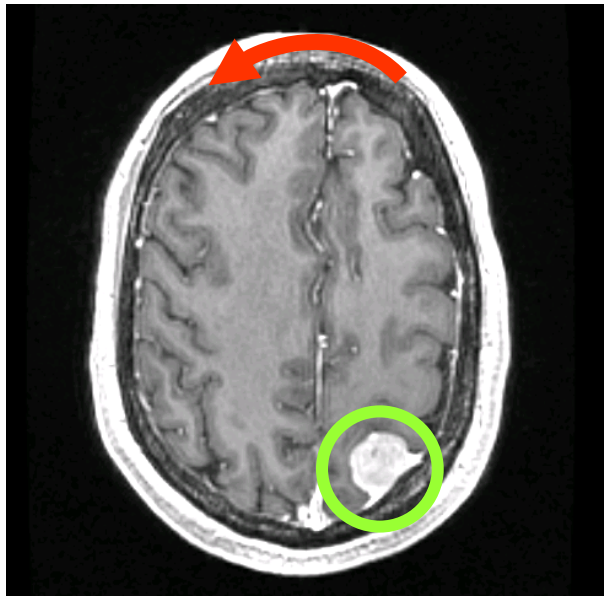
Konukoglu et al. ,“Monitoring Slowly Evolving Tumors”, ISBI 08

# Inconsistency Between Scans

1st Scan

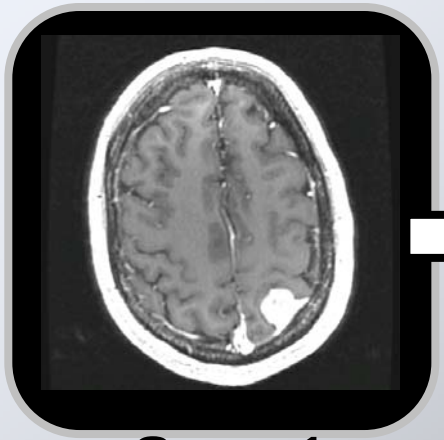


2nd Scan



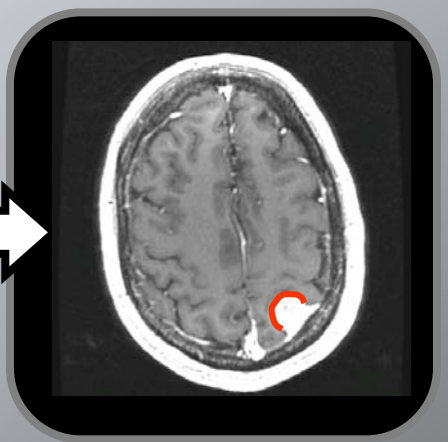
- **Changes in Head Position**
- **Artifacts through Image Acquisition**

# Mission

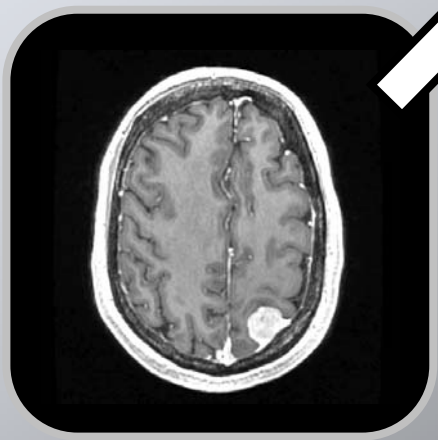


Scan 1

**Tool**



Growth



Scan 2

- semi-automatic quantitative measures derived from MRI
- compatibility with clinical requirements

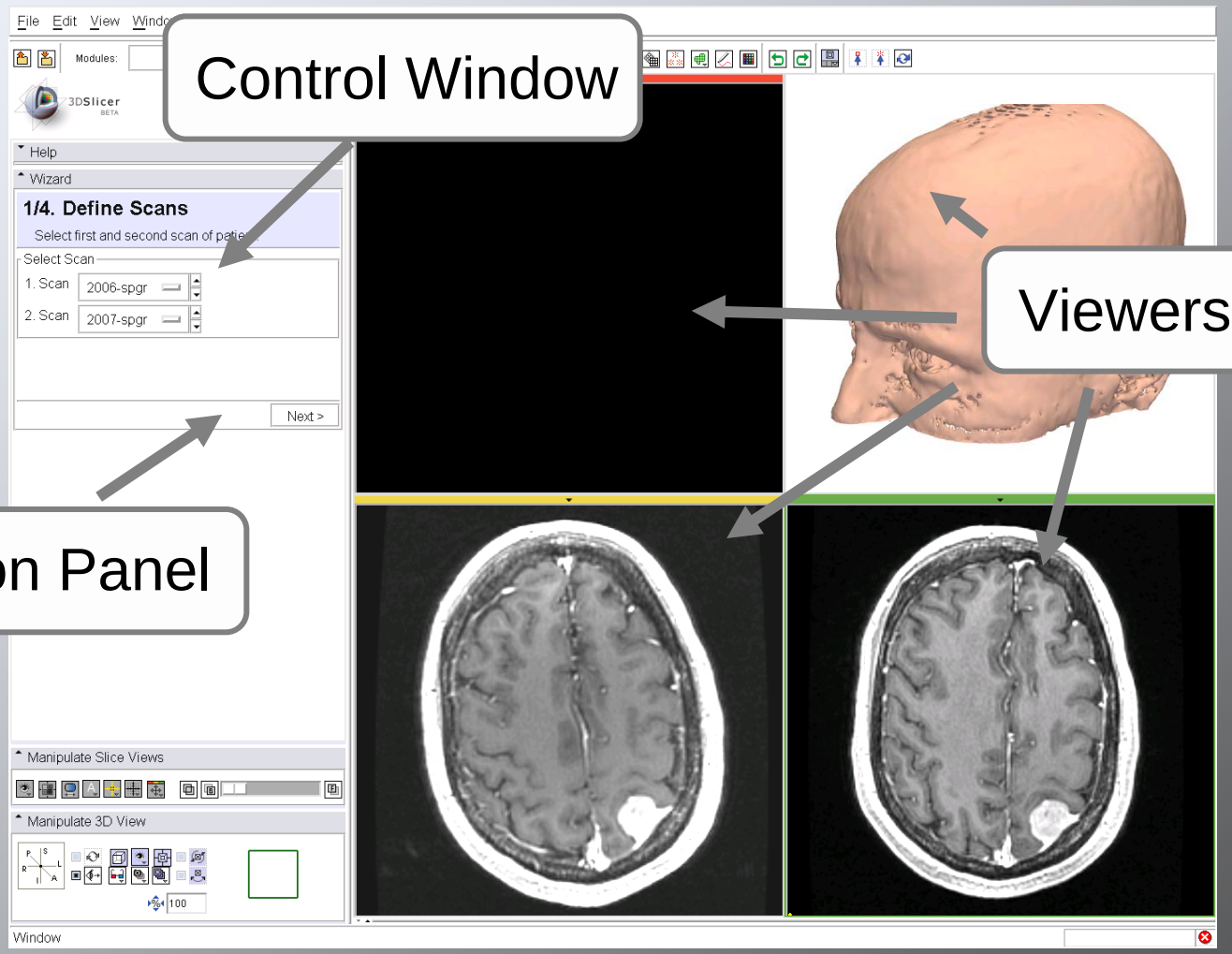
# Workflow

The implementation is based on a workflow approach

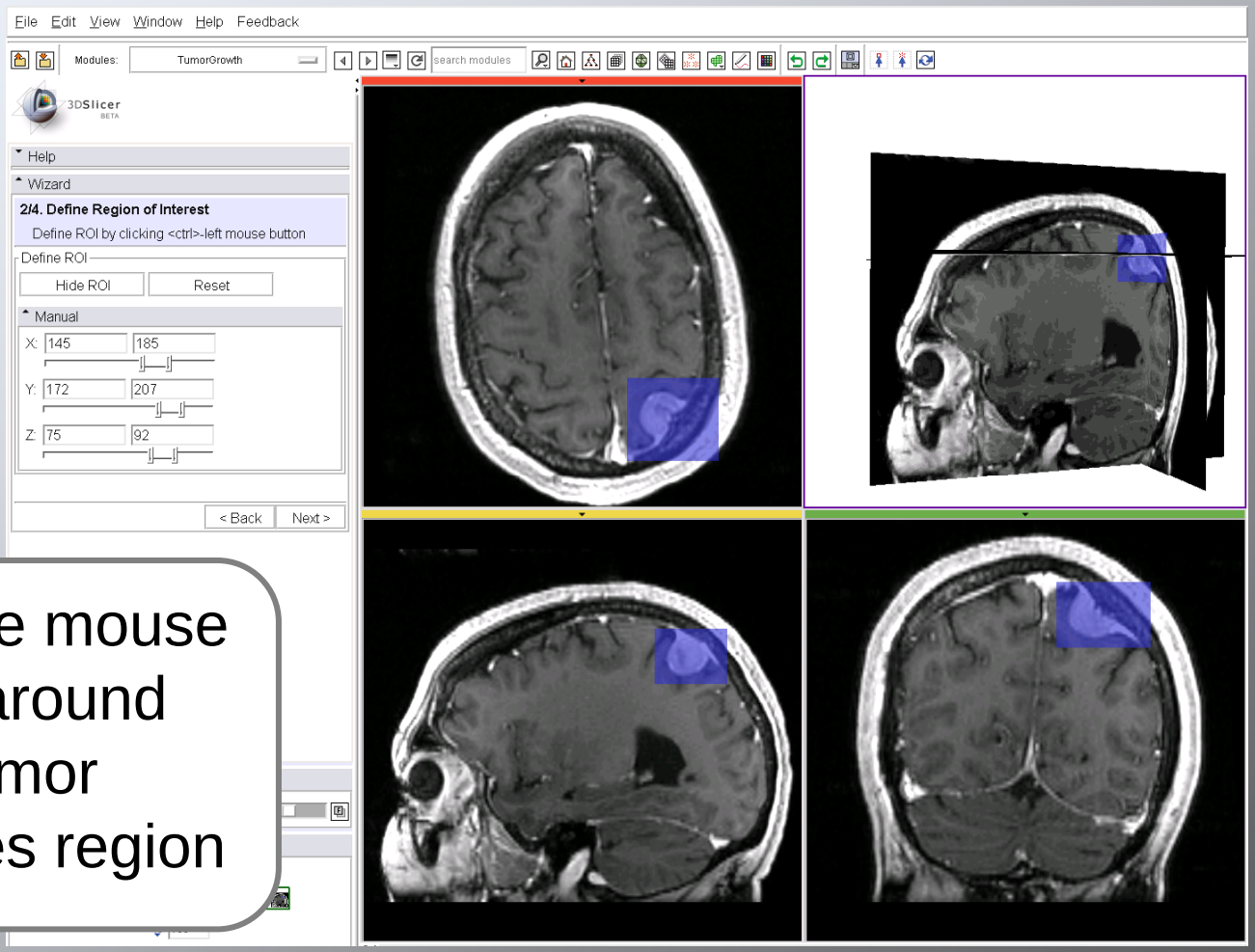
- Step 1: Select scans
- Step 2: Define tumor region
- Step 3: Segment tumor
- Step 4: Chose tumor metric

Automatic change detection is completed in less then 5 minutes

# Step1: Select Scans

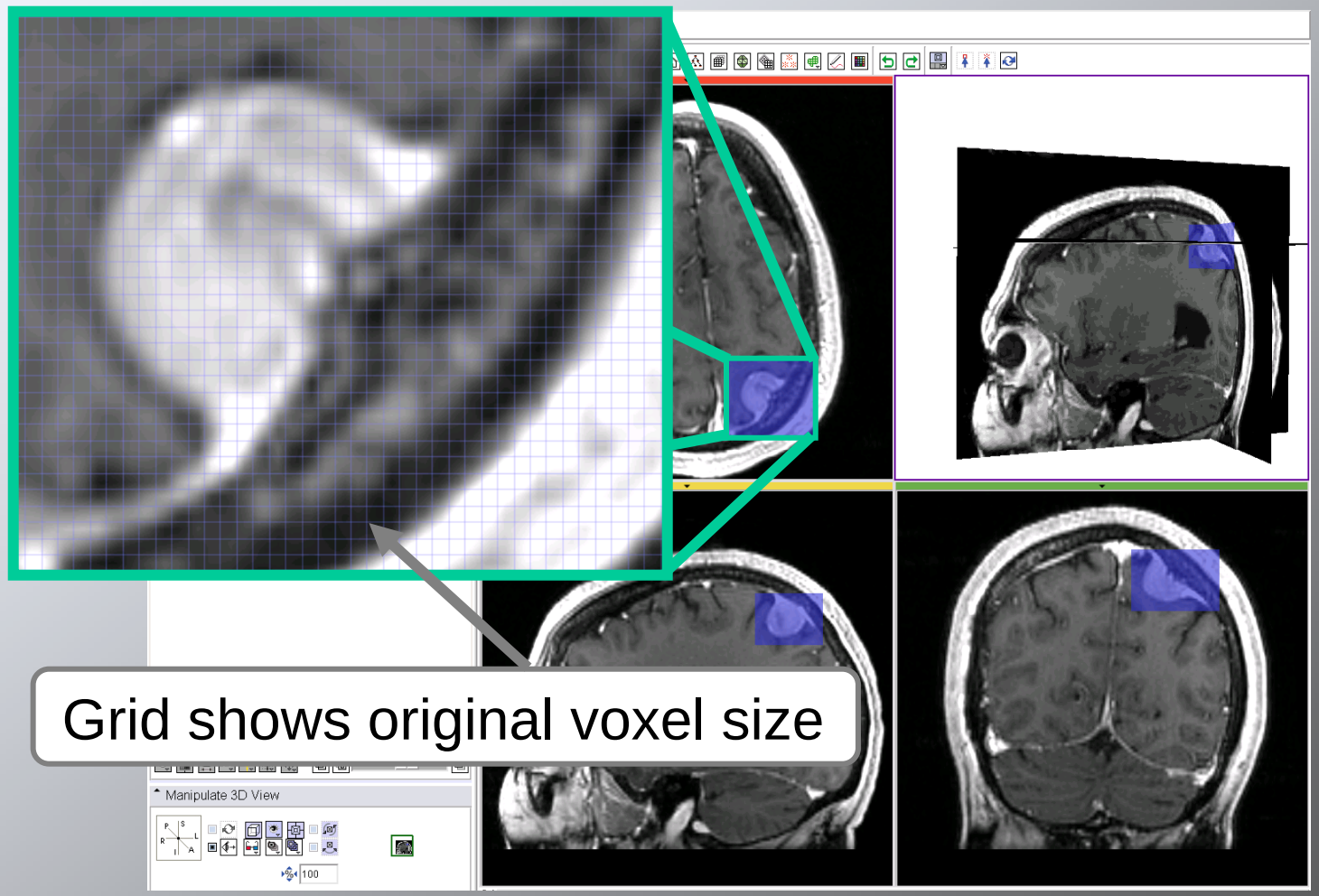


# Step 2: Define ROI in Scan 1



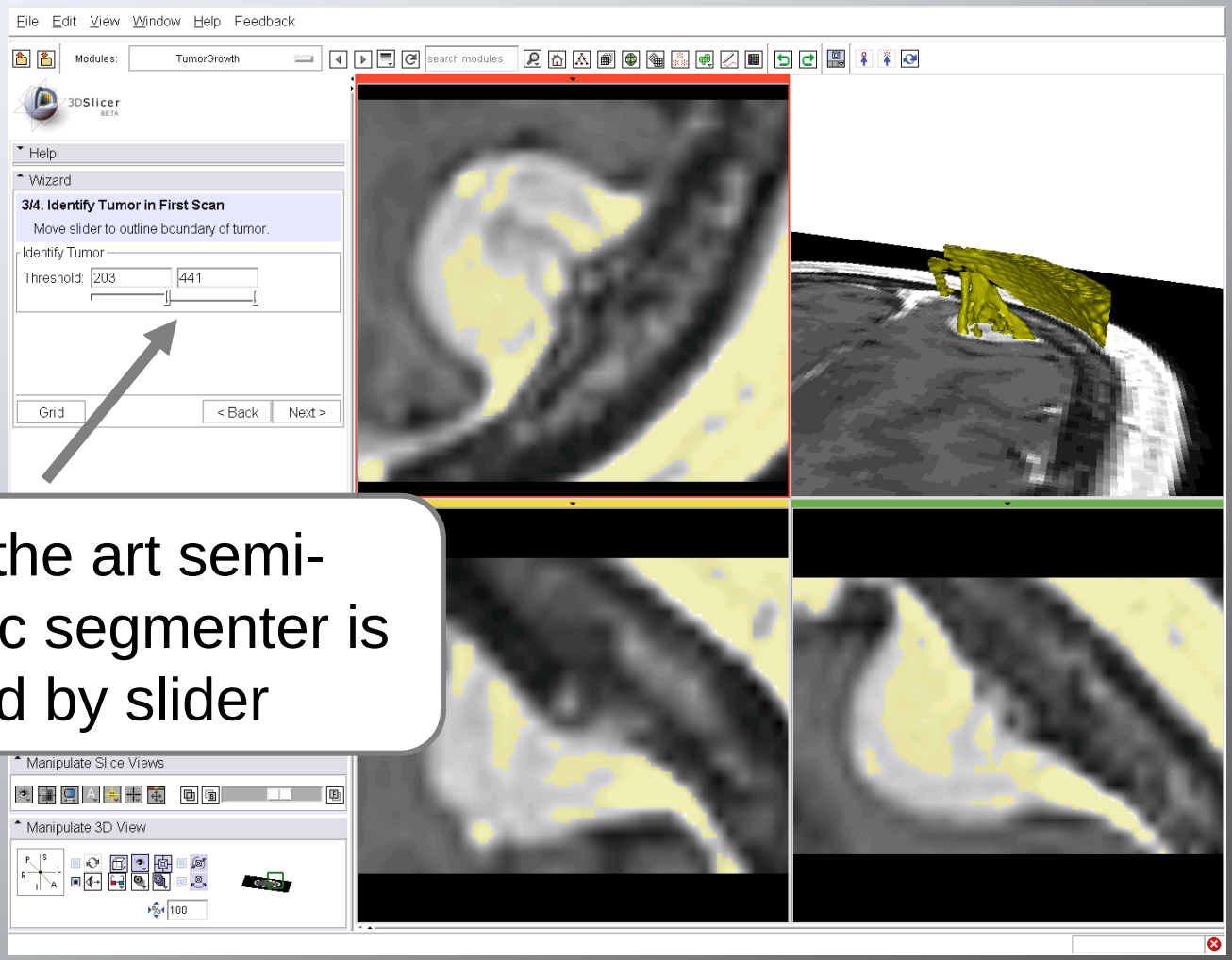

Simple mouse click around the tumor defines region

# Step 3: Zoom into ROI



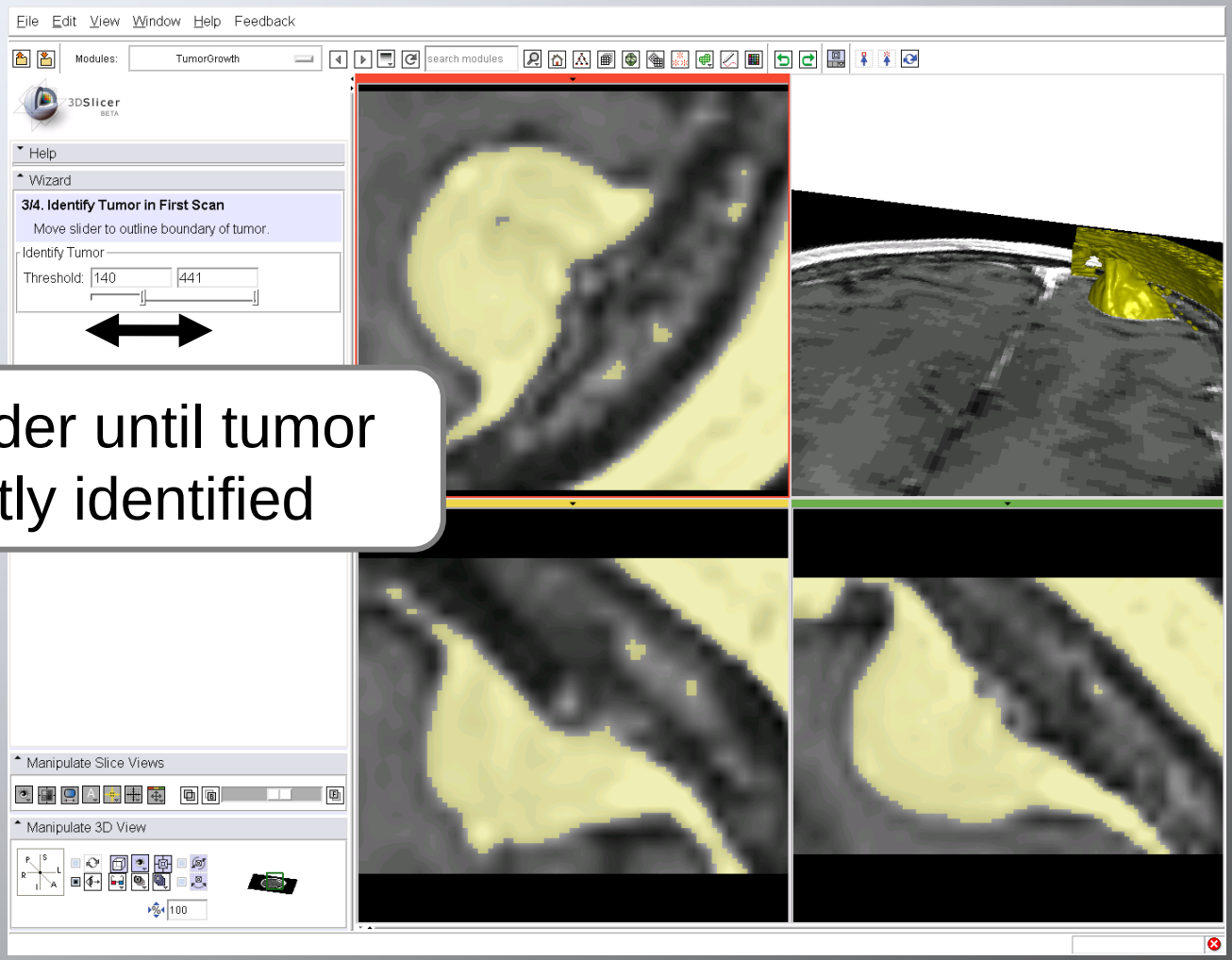

Grid shows original voxel size

# Step 3: Outline Tumor



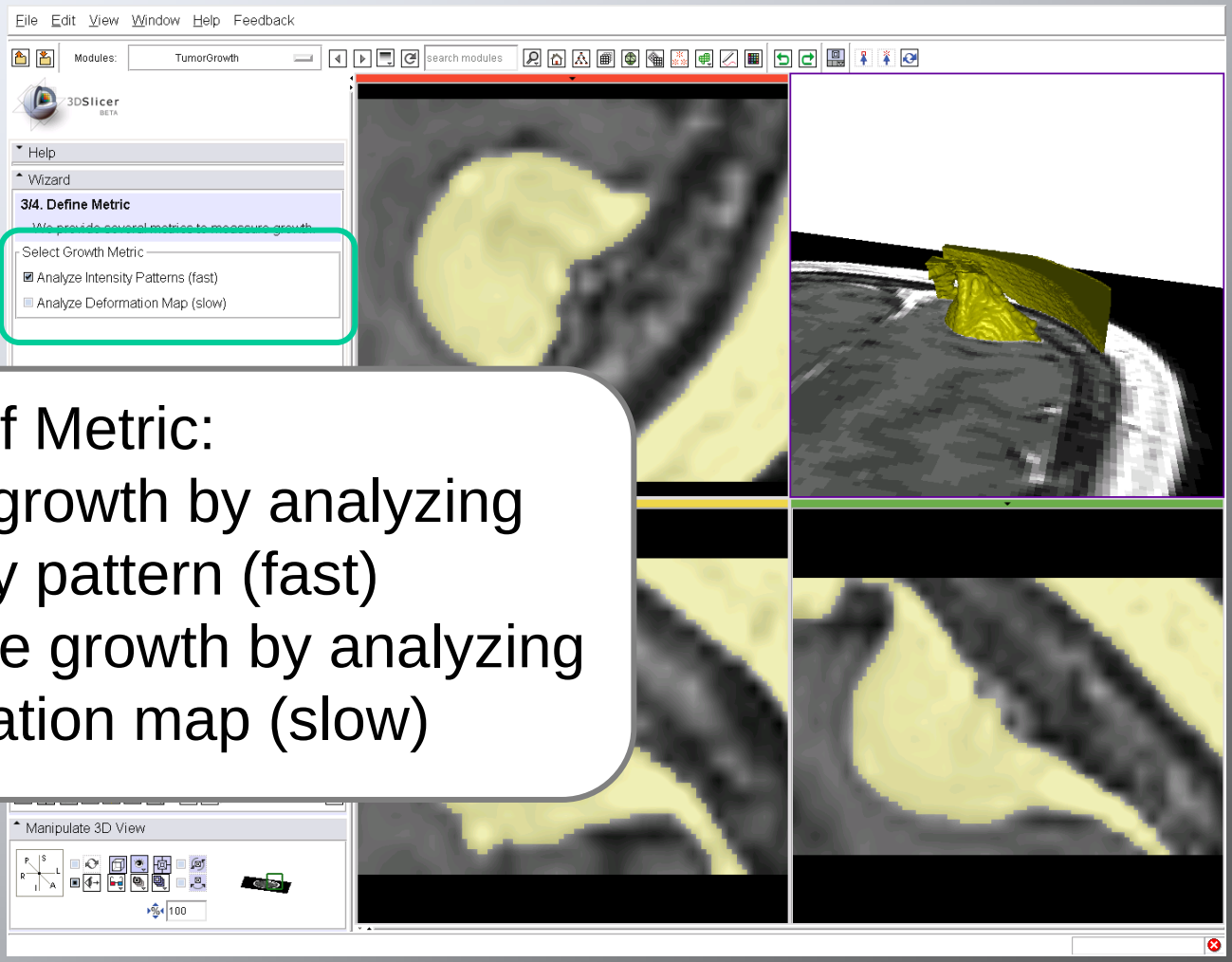

State of the art semi-automatic segmenter is calibrated by slider

# Step 3: Outline Tumor




Move slider until tumor is correctly identified

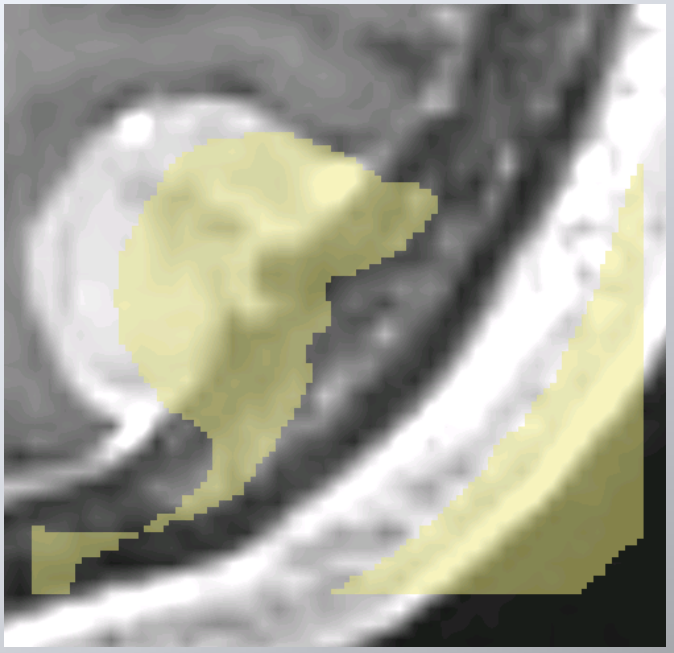
# Step 4: Select Metric



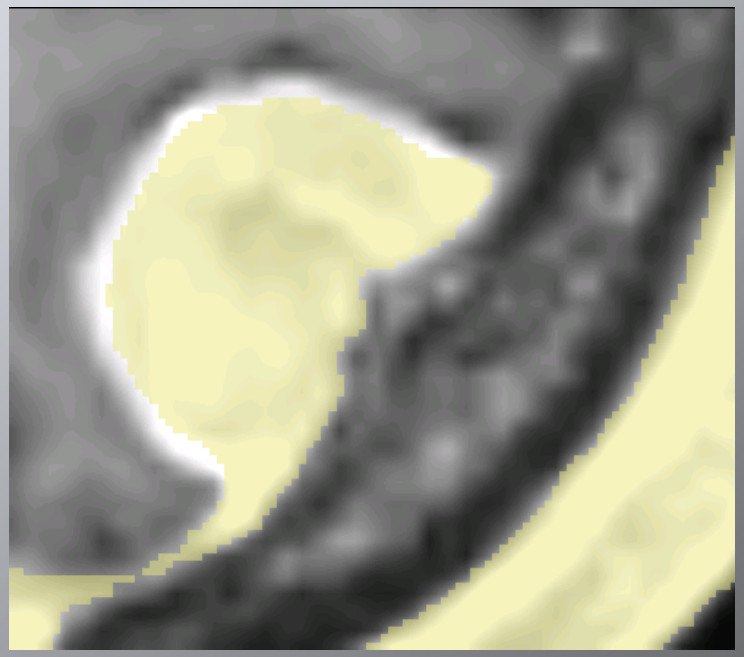

Choice of Metric:

- Detect growth by analyzing intensity pattern (fast)
- Measure growth by analyzing deformation map (slow)

# Step 5: Analysis - Registration



Before

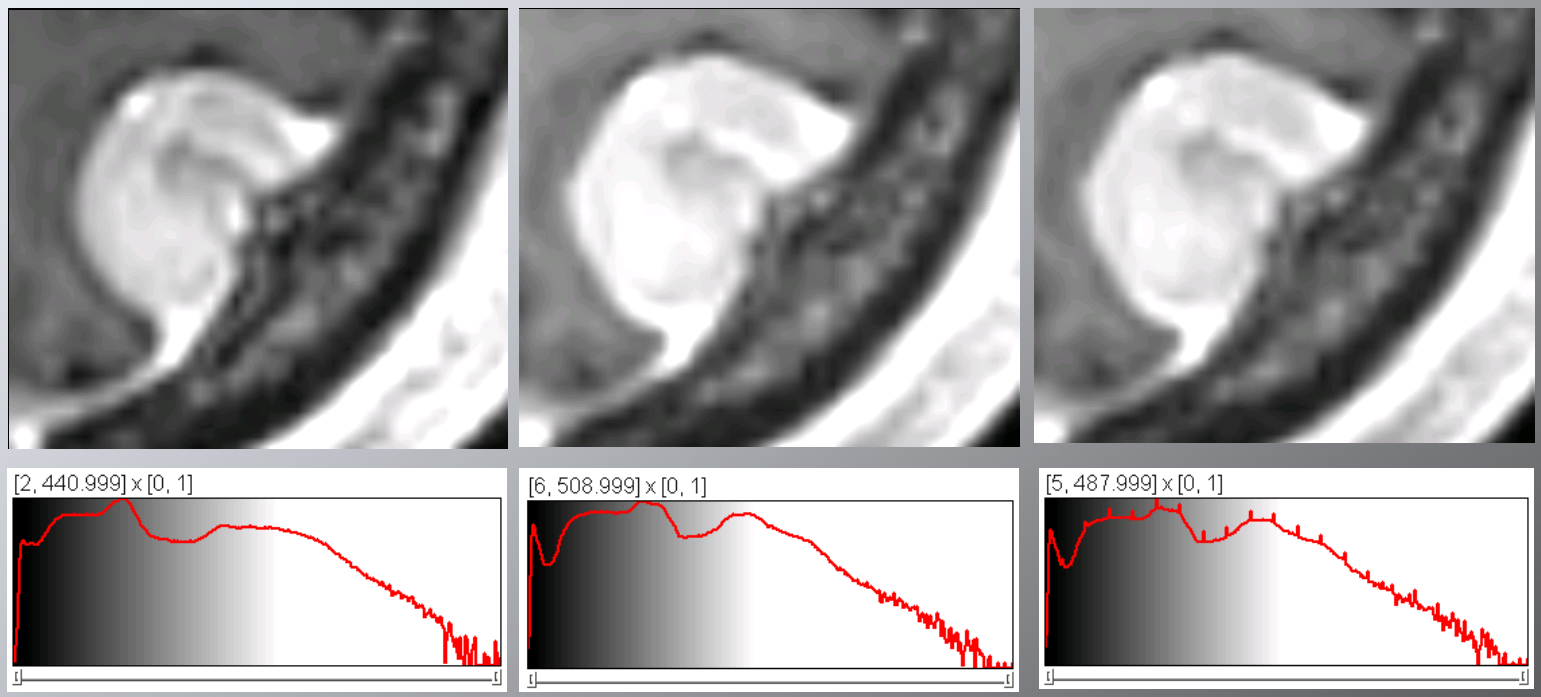


After

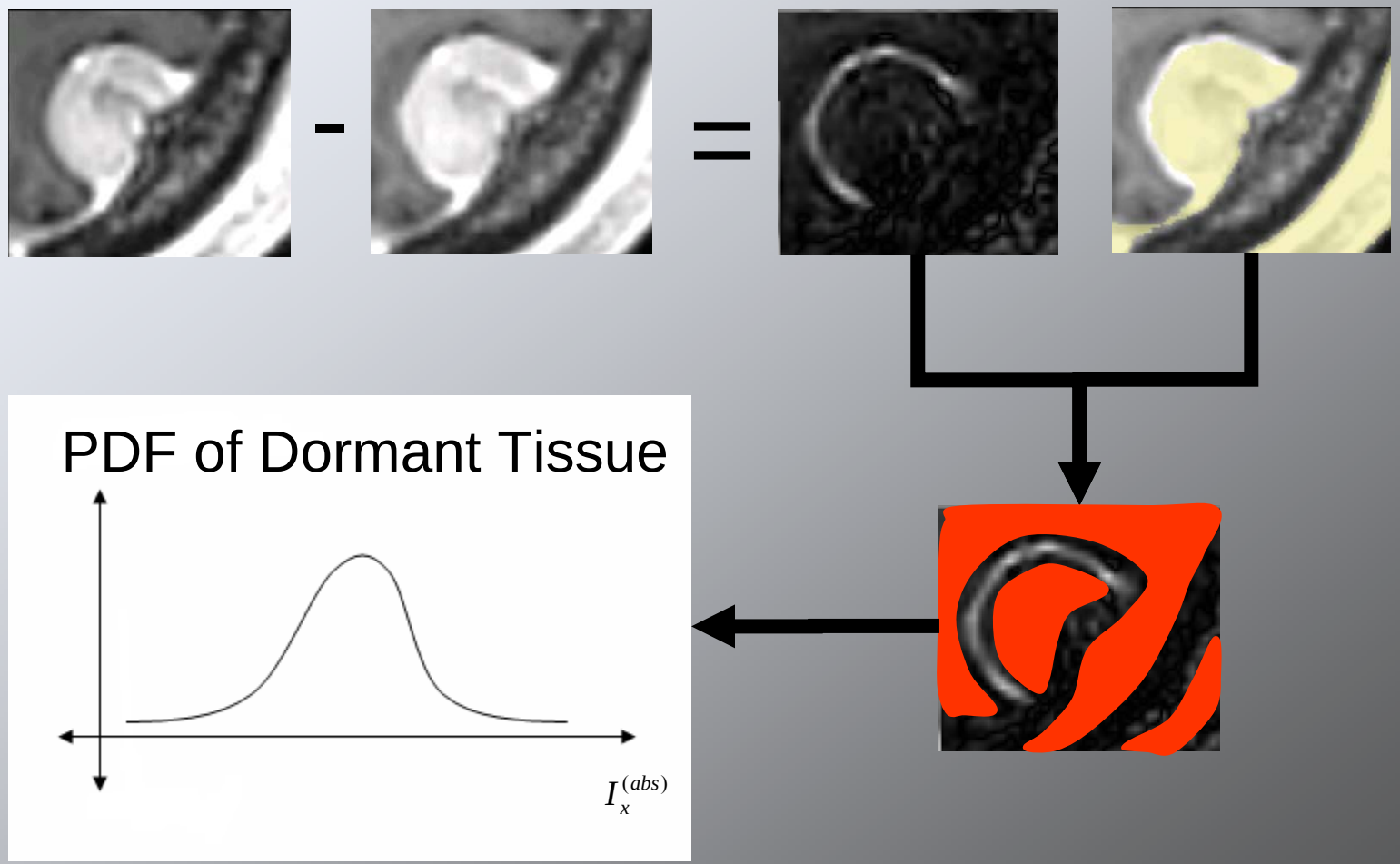
Volume Preserving Registration

# Step 5: Analysis – Normalize Intensities

Scan 1 | Scan 2 | Scan 2 - Norm

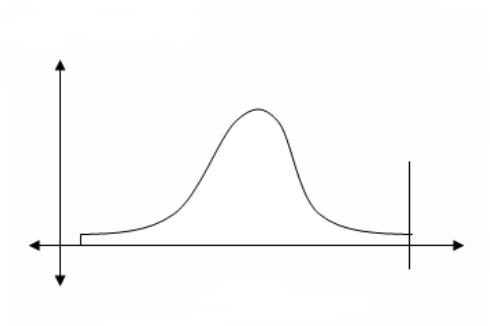


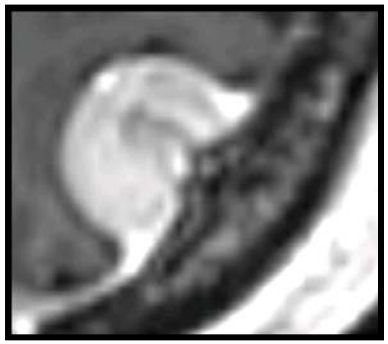
# Statistical Model of Dormant Tissue

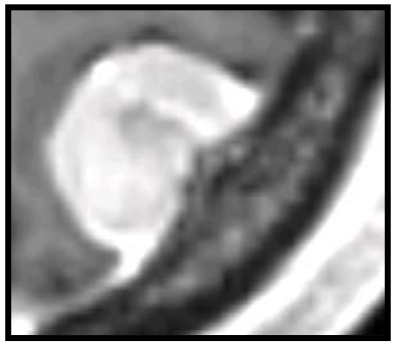


# Step 5: Analysis – Adjust Sensitivity

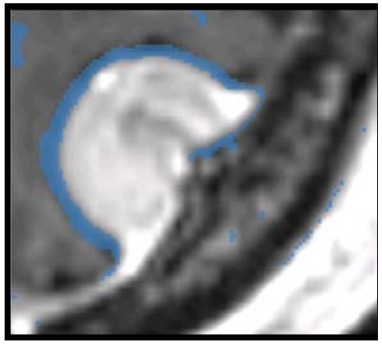
Data





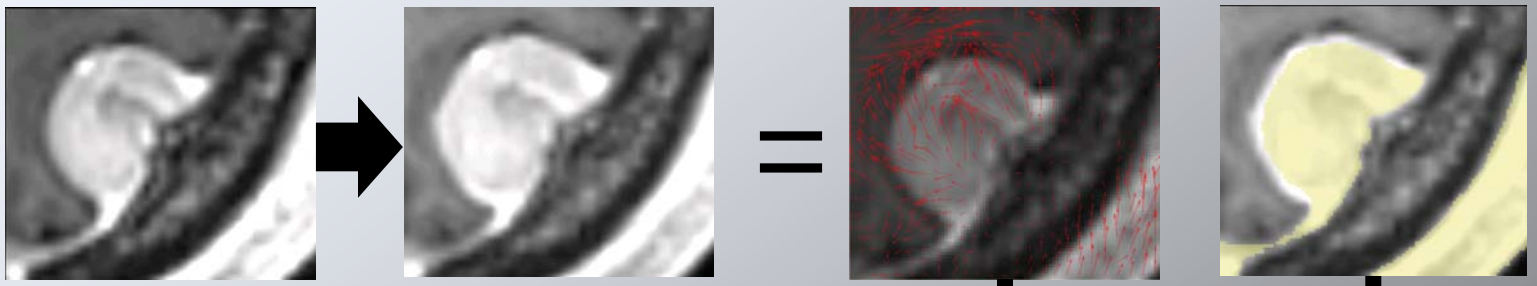


Analysis



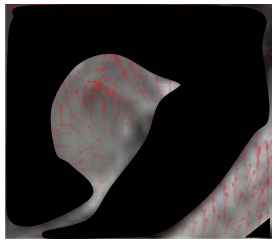
Mode : Aggressive
Growth ($mm^3$) : 2239
Growth (voxel): 1819

# Analyze Deformation Map



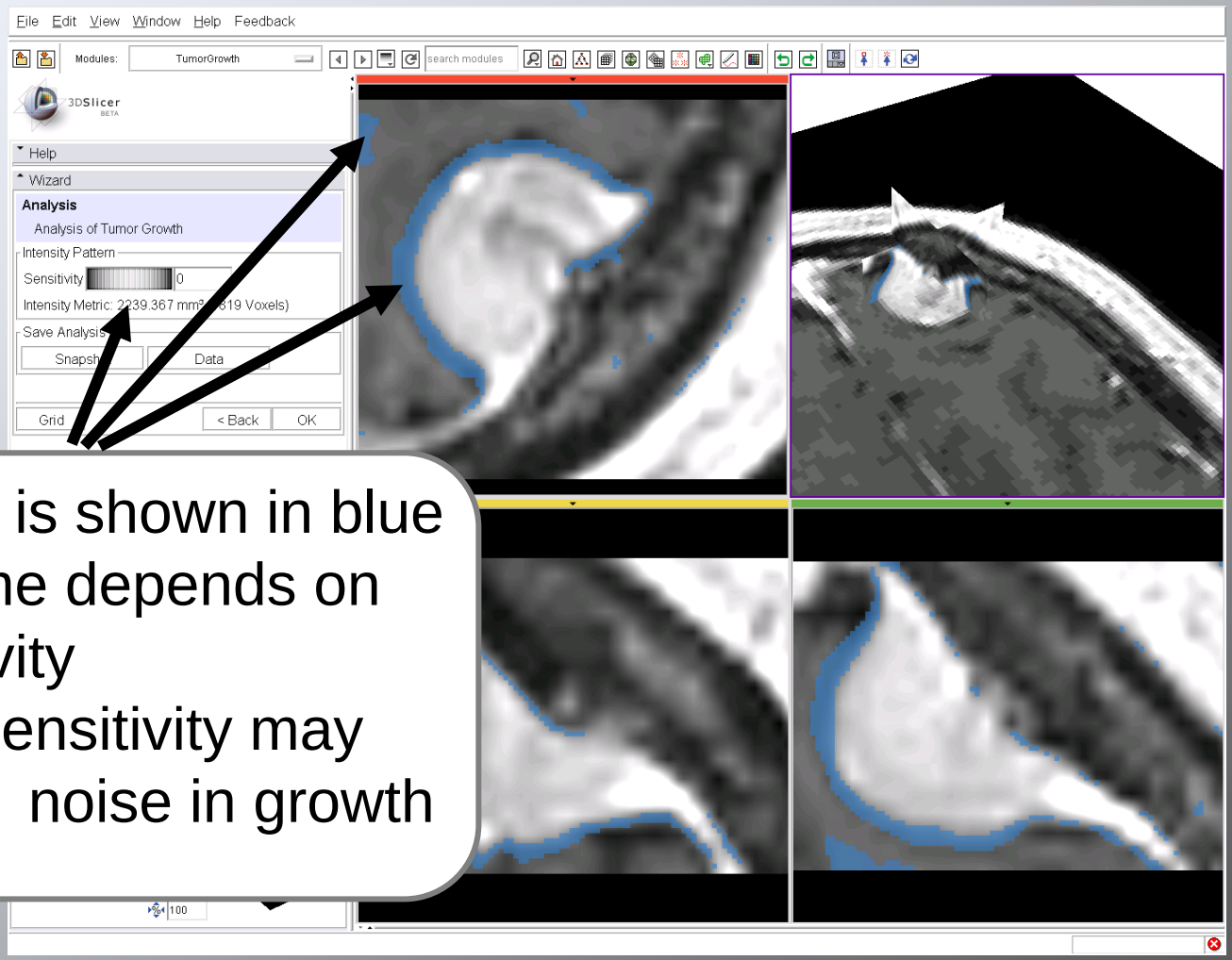
Compute deformation field using diffeomorphic demons

Mode : Segmentation
Growth ($mm^3$) : 764
Growth (voxels): 619



Mode : Jaccobian
Growth ($mm^3$) : 887
Growth (voxels): 718

# Step 5: Analysis – Adjust Sensitivity




- Growth is shown in blue
- Outcome depends on Sensitivity
- Small sensitivity may include noise in growth

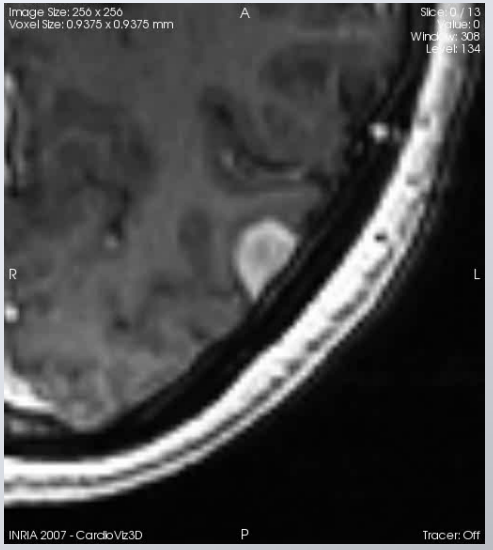
# Imaging

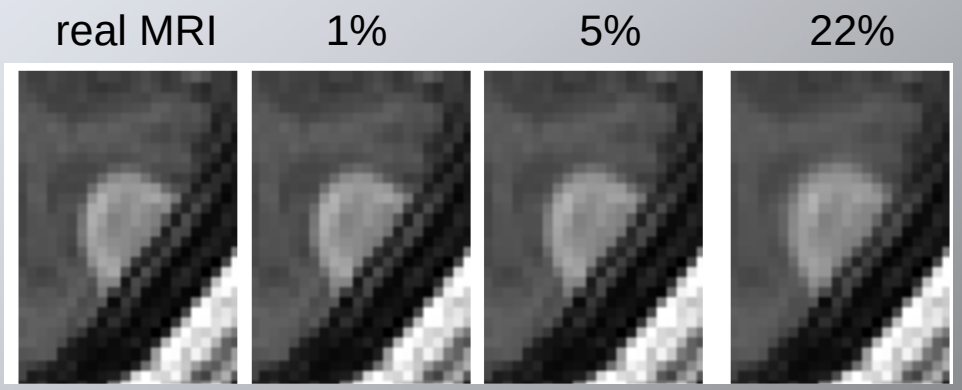
Developed a protocol that is compatible with clinical work and can be used for image analysis

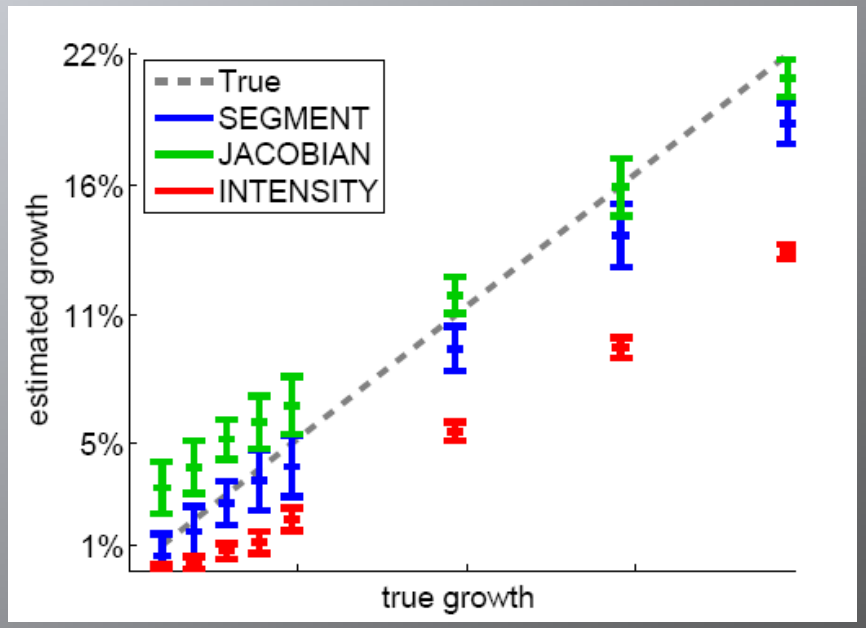
- Axial 3D SPGR T1 post Gadolinium
- Voxel dimension: 0.94mm x 0.94mm x 1.20mm
- FOV: 240mm Matrix: 256 x 256
- Scan time: 8 mins on 1.5T

IRB approval was not required

# Synthetic Experiment



# Test Database

Our training data base consists of

- 8 subjects scanned twice
- 1 subject scanned three times

| Case | EXPERT | | INTENSITY | | JACOBIAN | | SEGMENT | |
|---|---|---|---|---|---|---|---|---|
| | % | $mm^3$ | % | $mm^3$ | % | $mm^3$ | % | $mm^3$ |
| 1 | 4.8 | 596 | 9.7 | 1202 | 3.6 | 447 | 3.5 | 433 |
| 2 | 5.4 | 883 | 4.2 | 677 | 8.16 | 1325 | 9.14 | 1483 |
| 3 | −0.4 | −2.5 | 0.7 | 3.9 | −1.1 | −6.3 | −2.3 | −13 |
| 4 | −7.3 | −743 | 2.9 | 299 | 16.2 | 1660 | 20.1 | 2063 |
| 5 | −23.3 | −77 | 17.1 | 57 | 38.1 | 127 | 36.7 | 122 |
| 6 | −6.3 | −323 | 0.26 | 13.3 | −11.8 | −608 | −13.7 | −706 |
| 7 | 0.1 | 6.33 | 2.7 | 174 | −0.9 | −58 | 0.8 | 53 |
| 8a | 5.3 | 71 | 0.4 | 5.7 | 5.1 | 69 | 5.0 | 68 |
| 8b | −1.9 | −25 | 0.1 | 1.3 | 1.5 | 20 | 1.4 | 18 |
| 9 | 38.9 | 1165 | 25.1 | 751 | 29.7 | 887 | 25.6 | 764 |

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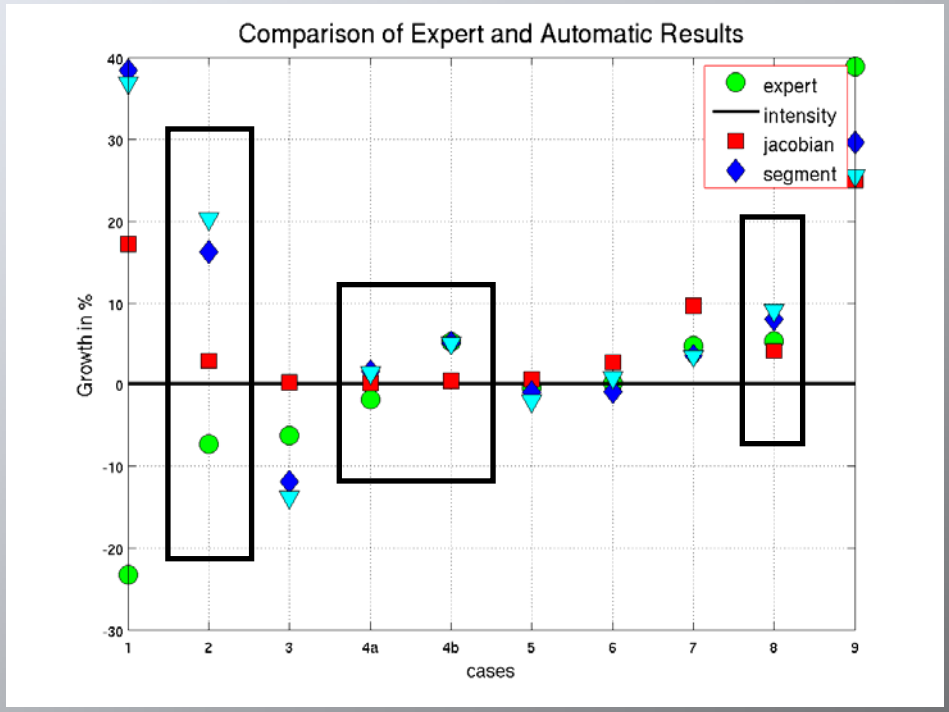


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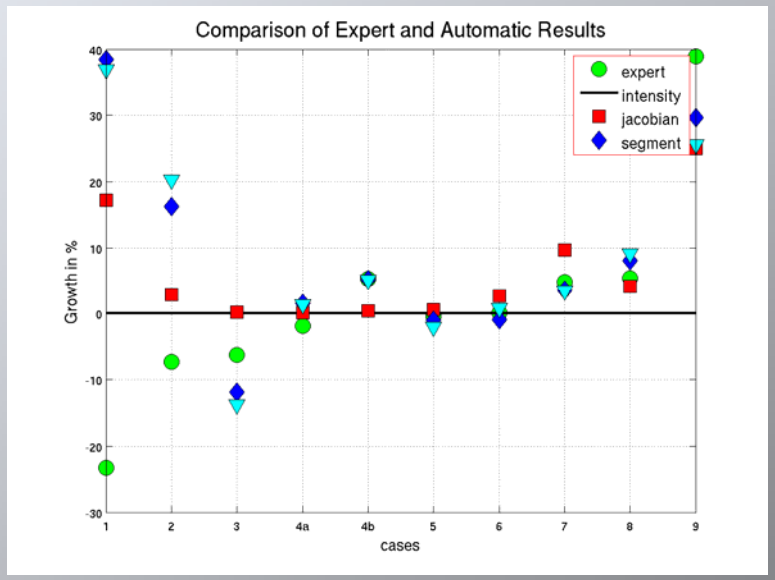
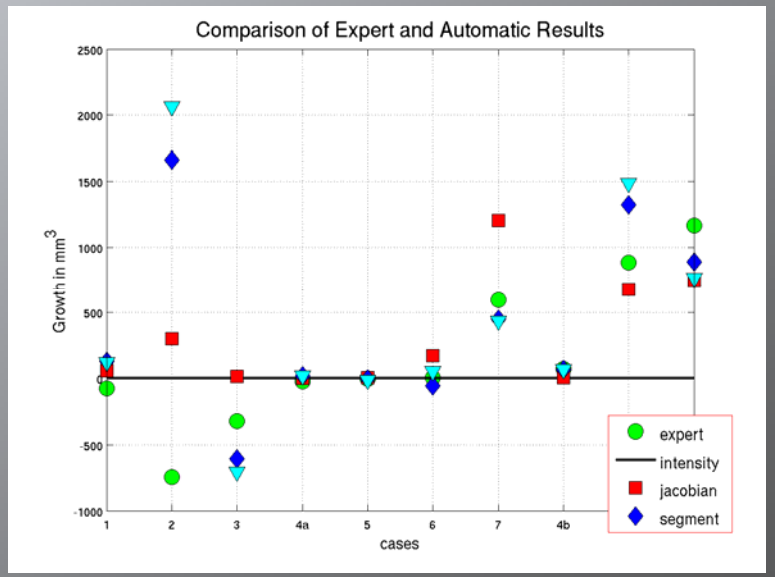
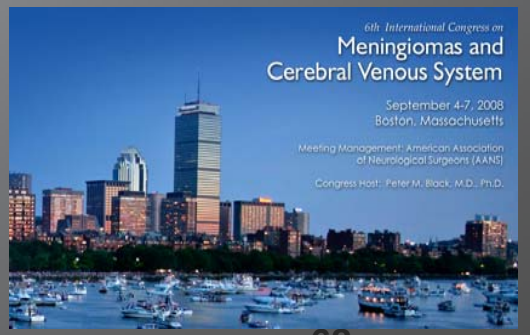


# Dissemination (In Progress)

- Tool will be accessible via www.slicer.org
- Konukoglu et al. ,"Monitoring Slowly Evolving Tumors", ISBI 08
- Pohl et al. , "Automatic Tumor Growth Detection" in Meningiomas A Comprehensive Text, In Press
- Online-Tutorial
  www.na-mic.org/Wiki/index.php/Slicer:Workshops:User_Training_101
- Hands-on training
  http://www.themeningiomaconference2008.org/



# Overview

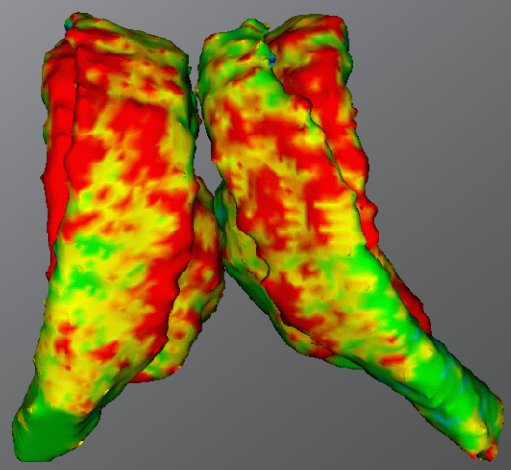
**Motivation**

**Software for Processing Images**

**Automatic Segmentation**

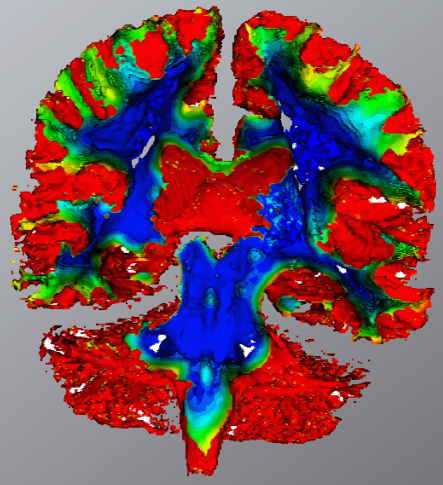
**Measuring Tumor Growth**

**Conclusion**



# Summary

- Publicly available software targeted towards medical imaging
- Automatic segmenter adoptable towards wide range of imaging problems
- Oncology  tool for tracking tumor growth



# Thank You




Surgical Planning Lab
BWH

Neurosurgery
Radiology
BWH


Psychiatry
Neuroimaging Lab
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