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ICTR The Johns Hopkins Institute for Clinical and Translational Research
where science and people connect

Principles of medical imaging data acquisition, registration, visualization and segmentation

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September 30, 2009

CTSA CLINICAL & TRANSLATIONAL SCIENCE AWARDS

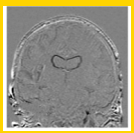
RSNA Radiological Society of North America Founded in 1915

Fundamentals of Image Processing for Extraction of Quantitative Metrics

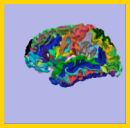
- **Anatomic (volume, label)**
- **Functional (DCE-MRI, fMRI or PET activation)**

Acquire

Visualize



Register

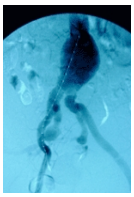


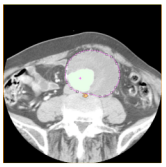
Segment
(and more…)

Available, reliable, reproducible, automatic or semi-automatic methods for each step.

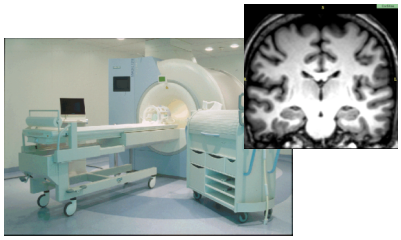
Visualization

X-Ray Fluoroscopy

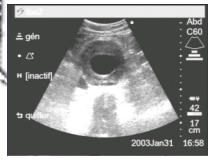




Computed Tomography

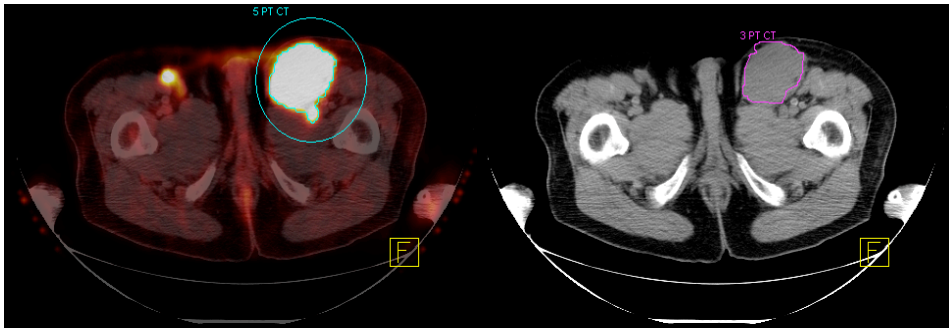


Magnetic Resonance Imaging



Ultrasound Imaging

Matching Image Acquisition Parameters to Target Biomarker

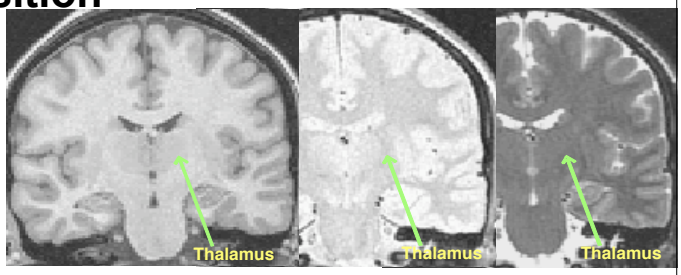


Primary outcome measures determine details of acquisition and analysis

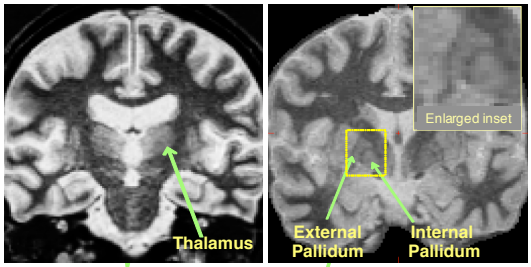
Example: Advances in Structural MRI

Image acquisition

– Traditional pulse sequences



– Novel pulse sequence improves subcortical region



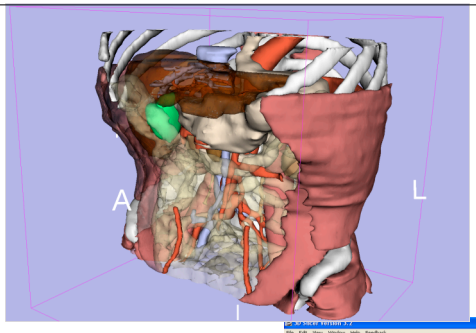
Fischl et al., 2006

Acquisition Standardization Issues

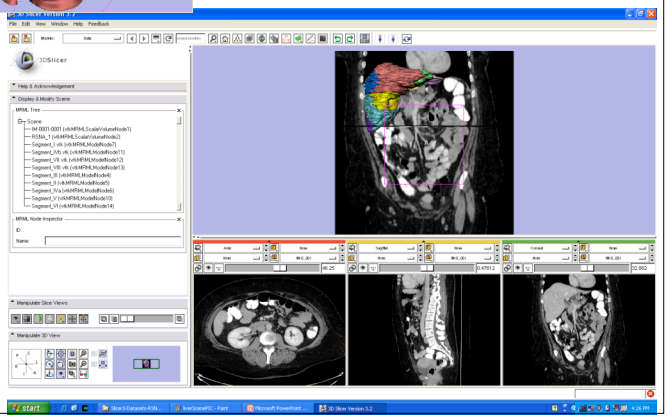
- **Within site**
  - **--Across hardware/ software upgrade**
- **Across sites**
  - **--Across vendor, platform, (field strength)**
- **Longitudinal**

Challenges of Advances in Image Acquisition

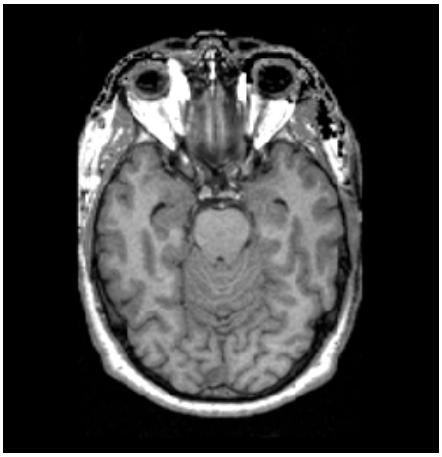
- **Subtle (and not so subtle) differences in scanner platform**
- **Compliance with acquisition protocol**
- **Need for multi-modal registration**
- **Increased resolution results in increased sensitivity to error contributed by image acquisition and analysis methods**



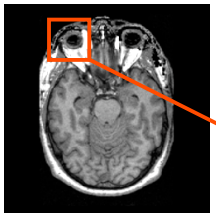
Interact in 3D to enhance data interpretation



What is an image ?

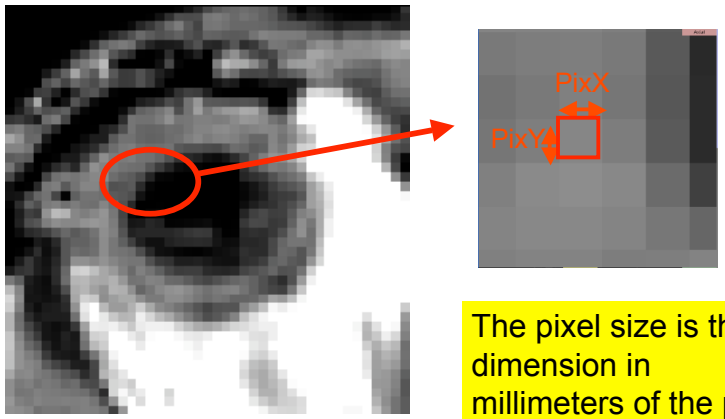


What is an image ?



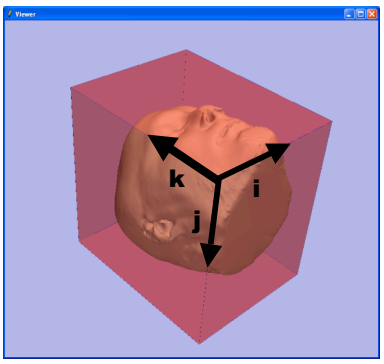
2D array
of pixels

Pixel Dimensions

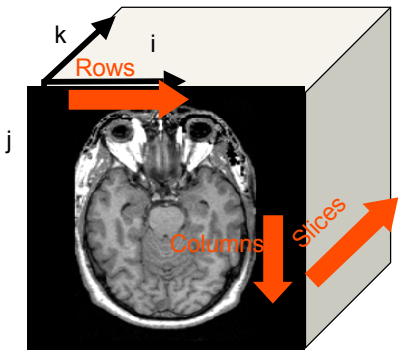


The pixel size is the dimension in millimeters of the pixels.

Data Representation

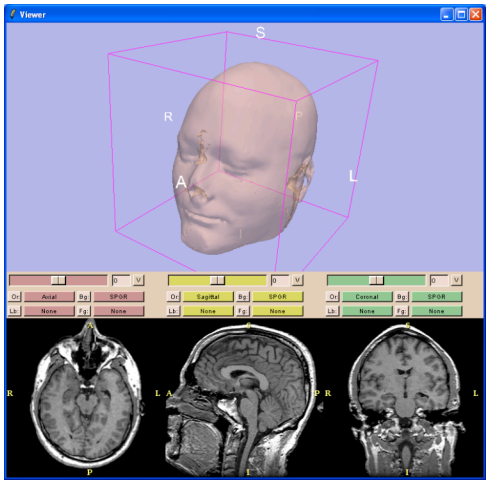


The result of the acquisition is a 3D Volume of data related to the patient.



The 3D volume is sampled on a 3D grid in the acquisition coordinate system (I,J,K).

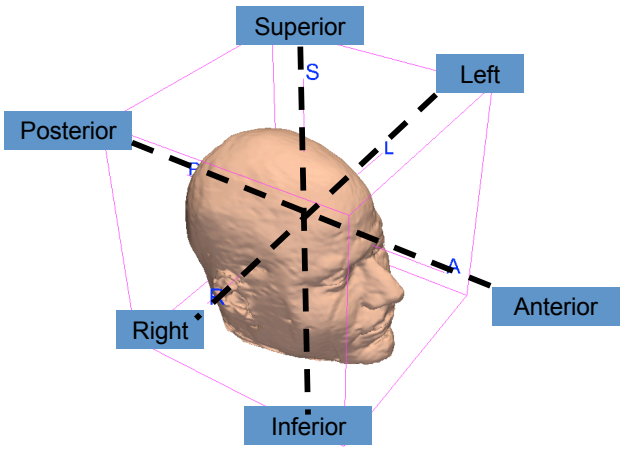
Anatomical Planes



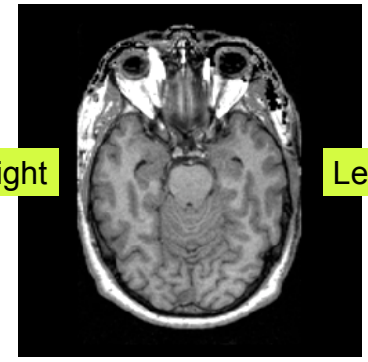
A 3D Viewer displays a model of the head.

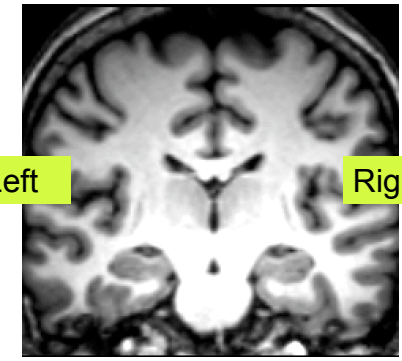
The 2D Viewers display the three anatomical planes (axial, sagittal, coronal).

Space Directions



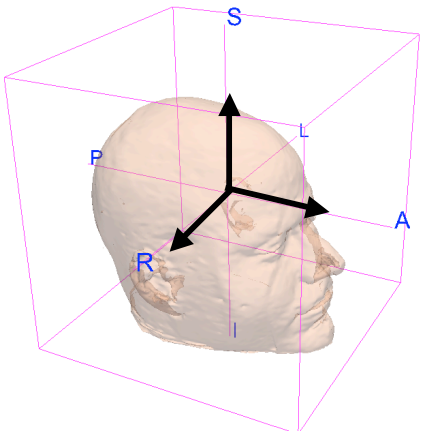
Space Orientation

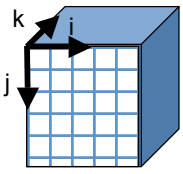




Axes for Spatial Coordinates

RAS: Right-Anterior-Superior





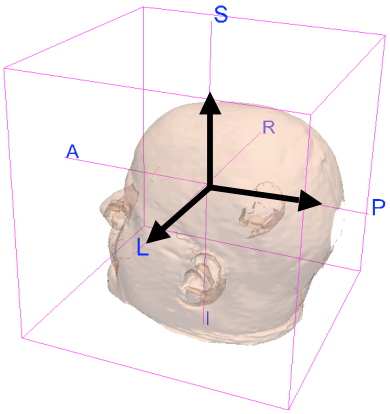
The index i in the file increases from the Left to the Right side of the Patient.

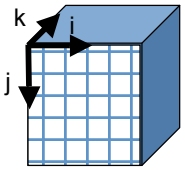
The index j in the file increases from Posterior to Anterior.

The index k in the file increases from Inferior to Superior.

Axes for Spatial Coordinates

LPS: Left-Posterior-Superior



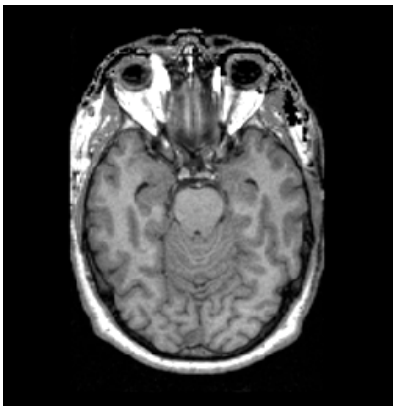


The index i in the file increases from the Right to the Left side of the Patient.

The index j in the file increases from Anterior to Posterior.

The index k in the file increases from Inferior to Superior.

DICOM 3.0 Standard



Example of DICOM header content

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0002,0001,File Meta Info Version=256
0002,0002,Media Storage SOP Class UID=1.2.840.10008.5.1.4.1.1.4.
0002,0003,Media Storage SOP Inst UID=0.0.0.0.
0002,0010,Transfer Syntax UID=1.2.840.10008.1.2.1.
...
0008,0060,Modality=MR
0008,0070,Manufacturer=GE MEDICAL SYSTEMS
0008,0080,Institution Name=1852796513
0008,0081,City Name=1852796513
0008,0090,Referring Physician's Name=1852796513
0008,0092,?=1852796513
0008,0201,?=-0500
0008,1010,Station Name=1852796513
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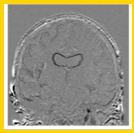
0008,103E,Series Description=anon
0008,1040,Institutional Dept. Name=1852796513
0008,1050,Performing Physician's Name=1852796513
0008,1060,Name Phys(s) Read Study=1852796513
0008,1070,Operator's Name=anon
0008,1080,Admitting Diagnosis Description=1852796513

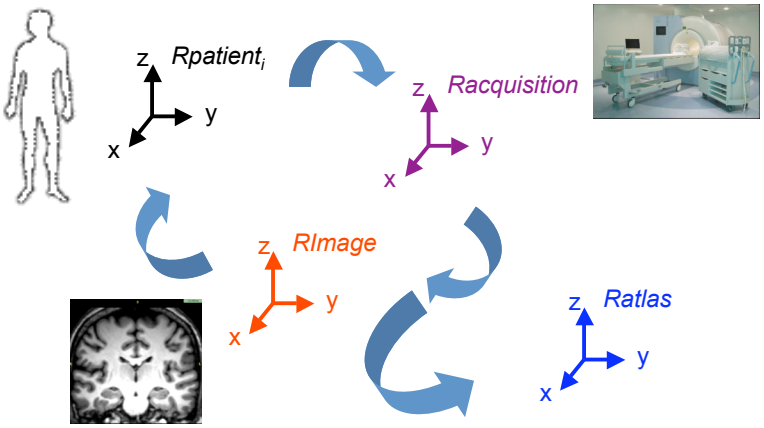
Image information

0010,0030,Patient Date of Birth=00000000
0010,0032,Patient Birth Time=000000
0010,0040,Patient Sex=O
0010,1010,Patient Age=000Y
.....
0028,0010,Rows=256
0028,0011,Columns=256
0028,0030,Pixel Spacing=0.937500 0.937500
0028,0100,Bits Allocated=16
0028,0101,Bits Stored=16
0028,0102,High Bit=15
0028,0103,Pixel Representation=1
.....
7FE0,0010,Pixel Data=131072

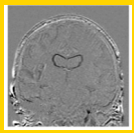
Registration



Registration is the process of transforming these three different spaces into a common reference frame

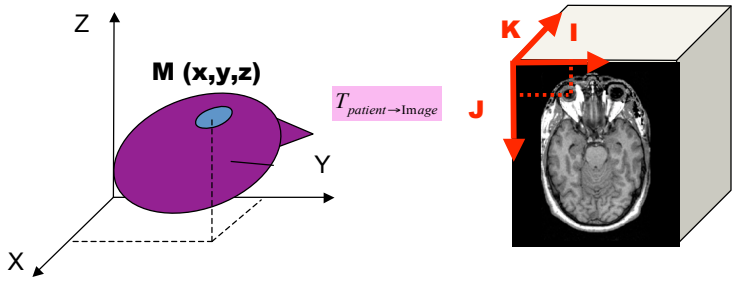


Patient → Image Transform



Patient Space

Image Space



M (x,y,z)

M(a,b,c)

Uses for Image Registration

Within or Intra-subject: images acquired at near or same time

Purpose: to combine functional and anatomical information of different imaging modalities

Examples: CT and MR for surgical planning

MR and PET/SPECT images of tracer uptake for localization of functional activity

Across or Inter-subject:

Purpose: To assess individual or group variability in some anatomical or functional measure

Examples: Responders vs. non-responders to treatment

Serial or Longitudinal: a sequence of images collected over time of the same subject(s)

Purpose: To assess change within a subject or group over time due to development, aging, disease progression and/or to monitor response to treatment.

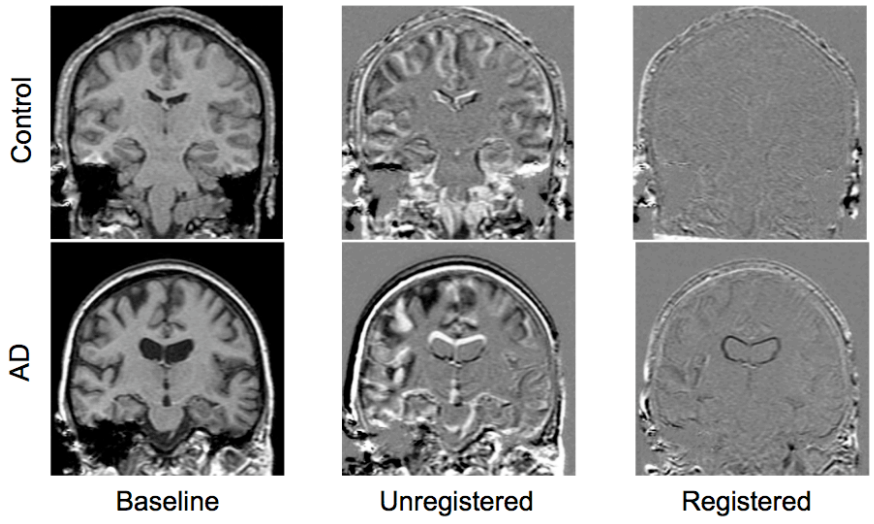
Examples: Deformation based morphometry (months), fMRI (minutes)

Subject to atlas:

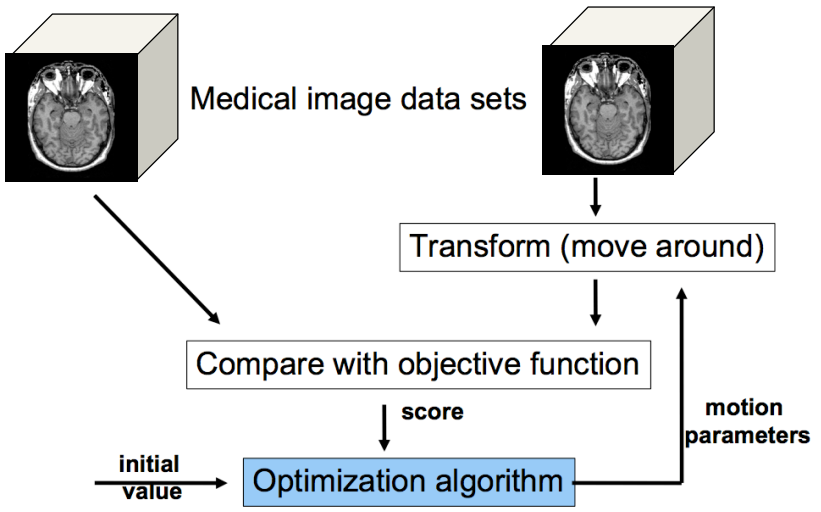
Purpose: To use population based information as priors to inform labeling or registration

Examples: Brain segmentation and parcellation, Boundary based registration

Why use registration? (two time points, same subject)



How a Registration Algorithm Works



What Characterizes a Registration Algorithm?

1) Similarity metric (objective function): Sum of Square Differences (SSD), MSD, Normalized Correlation Ratio (n)CR, Normalized Correlation Coefficient (n)CC, Mutual Information (MI), …

2) Transformation: affine, piecewise linear, nonlinear …

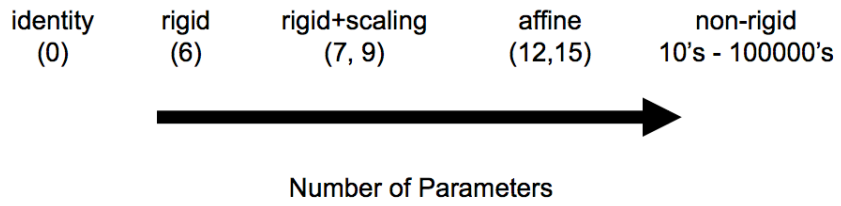
3) Regularization: multi-resolution/scale, Gaussian blur, …

4) Optimization algorithm: simplex, gradient descent, ….

5) Interpolation: nearest-neighbor (for label maps), trilinear, cubic, sinc, …

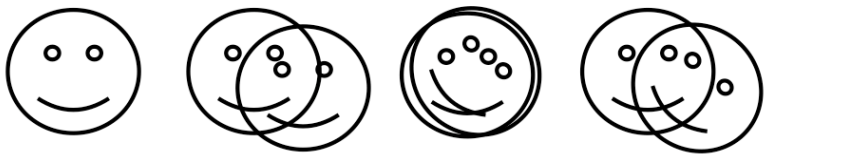
Transformation Models

Transformations are described by the number of parameters (often referred to as Degrees of Freedom or DOF)



Rigid-body Transformation

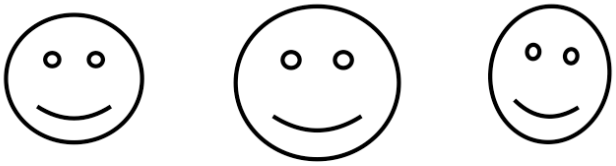
- Compensates for global patient repositioning
- Preserves distances, planes and angles.



- Appropriate for:
  - brain, bone, optically tracked surgical instruments
  - often used to initialise non-rigid registration

Affine Transformation

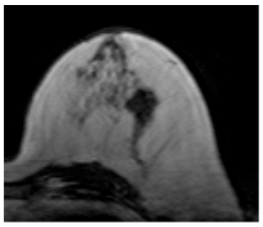
- Compensates for additional global size changes and shears



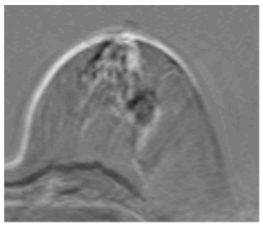
Scaling (3)

Shear (3+3)

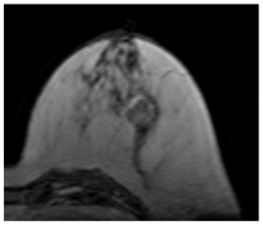
Non-rigid Transformation



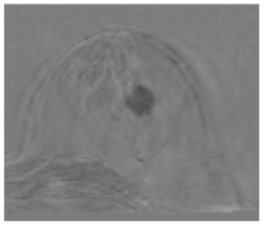
Pre-contrast



Subtraction of pre- and post-contrast



Post-contrast



Subtraction of pre- and post-contrast after non-rigid registration

Challenges for Image Registration

•Matching the spatial scale of the tissue of interest (e.g. cortical thickness 1-5 mm)

•Image intensity inconsistencies

Contrast difference (e.g. T1 vs T2 MRI)

Distortion differences (e.g. EPI MRI vs MRI or PET)

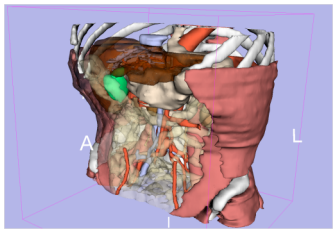
• Image intensity inhomogeneities (e.g. due to receiver coil characteristics)

Segmentation Goals

Identify or label structures present in the image for:

- Quantitative measurement of volume, shape or location

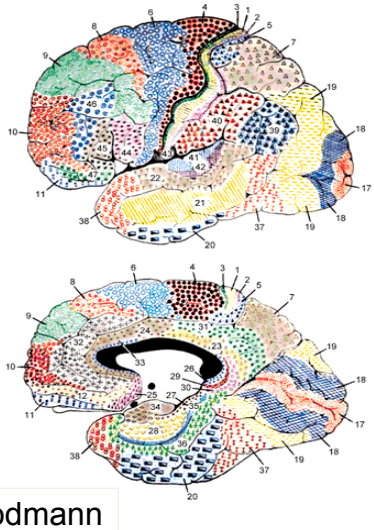
- Provide boundary for visualization by surface rendering



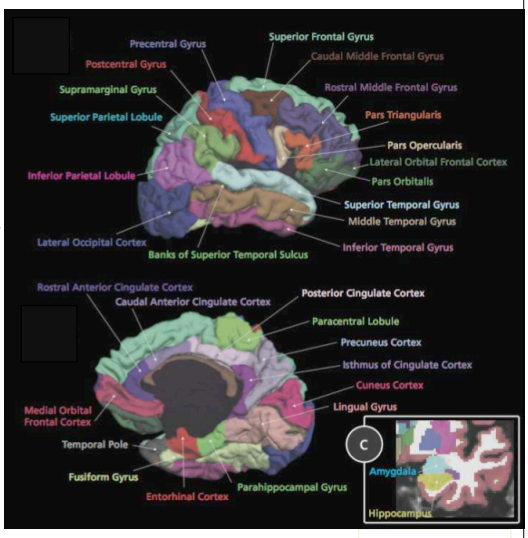
Segmentation Methods

- **Interactive or manual delineation**
- **Supervised approaches with user initialization**
  - Thresholding
  - Clustering
  - Region growing
  - Edge detection
- **Atlas based alignment with a template**
- **Statistical pattern recognition**

Structural localization of function

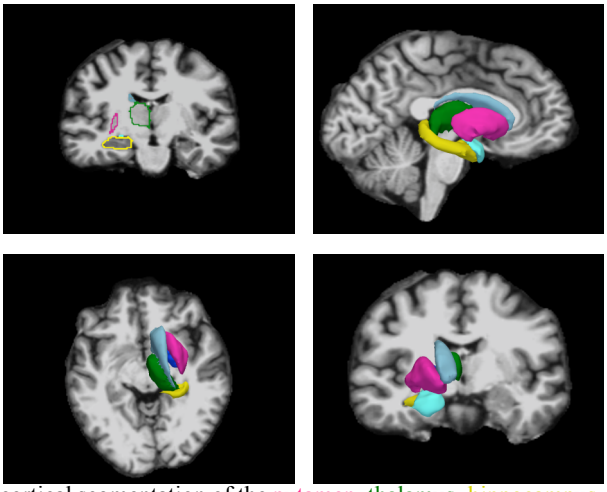


Brodmann 1909



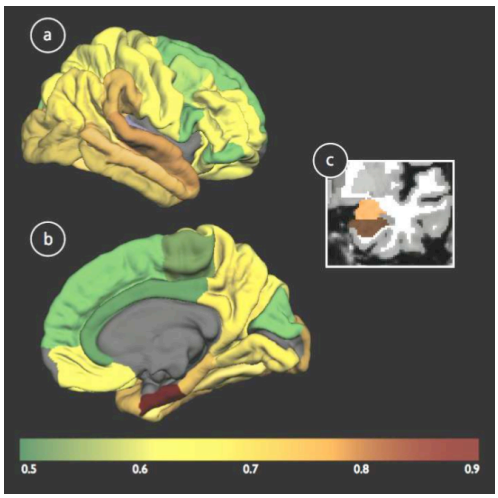
Desikan 2009

Automatically segmented structures



Freesurfer subcortical segmentation of the putamen, thalamus, hippocampus, amygdala, and caudate. Image constructed using Slicer 2.7 (www.slicer.org).

Automated Freesurfer segmentation output predicts MCI



- **Entorhinal cortical thickness**
- **Hippocampal volume**
- **Supermarginal gyrus thickness**

Desikan, et al in press, Brain

Technical Validation of Registration

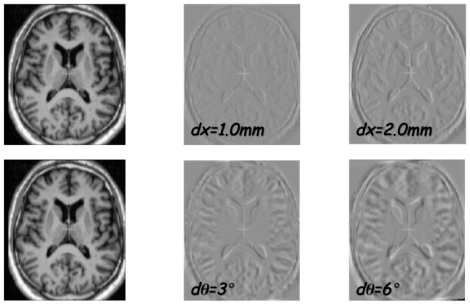
Robustness:
- Measurement precision

Consistency:
- Circular (invertible) transformations

Visual assessment:
- Subtraction imagines, overlays, landmarks

Gold Standard:
- Implanted/attached markers, landmarks

Simulation of ground truth:
- misregistration followed by motion recovery



Validation of Registration, Segmentation or any Image Processing Method

Prior to entering clinical practice:

Technical validation
- Speed, robustness, accuracy, reliability

Clinical validation
- Utility, improved diagnosis and patient management

FDA approval, incorporation into commercial system (?)
- Liability

Acknowledgements

The Johns Hopkins Institute for Clinical and Translational Research
ICTR
where science and people connect

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Daniel Rueckert, PhD (Imperial College London)
Simon Warefield, PhD (CHB)

National Alliance for Medical Image Computing
NIH U54EB005149

CTSA CLINICAL & TRANSLATIONAL SCIENCE AWARDS

RSNA Radiological Society of North America Founded in 1915