BIC Lecture & NEUR570,
September 23, 2013

Structural Image Preprocessing

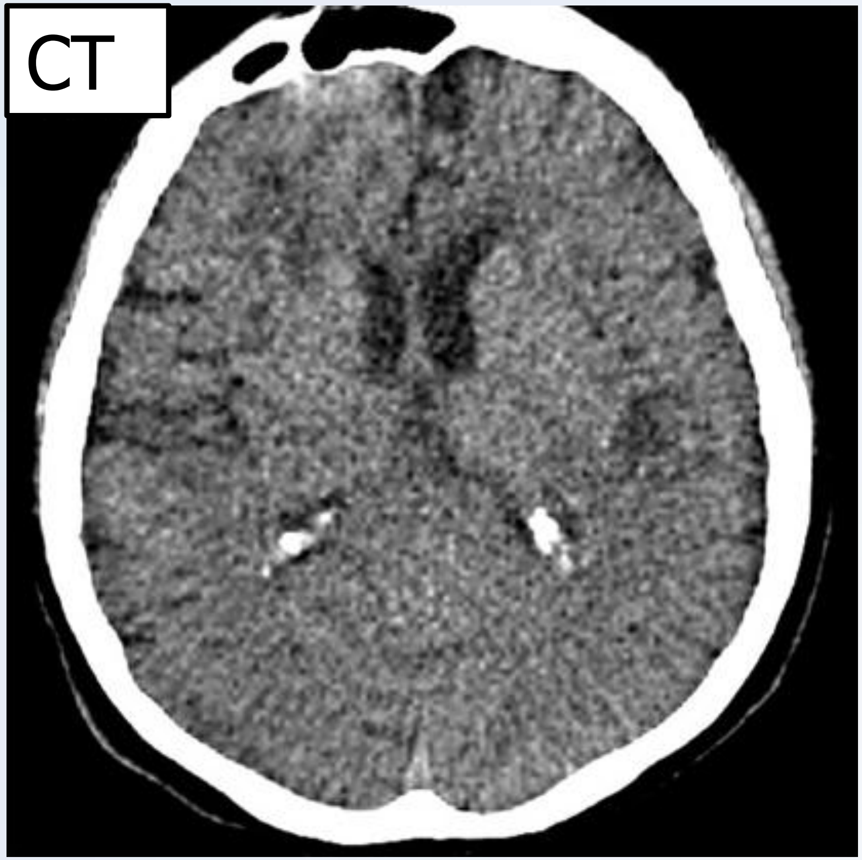
Kunio Nakamura, PhD
kunio.nakamura@mcgill.ca

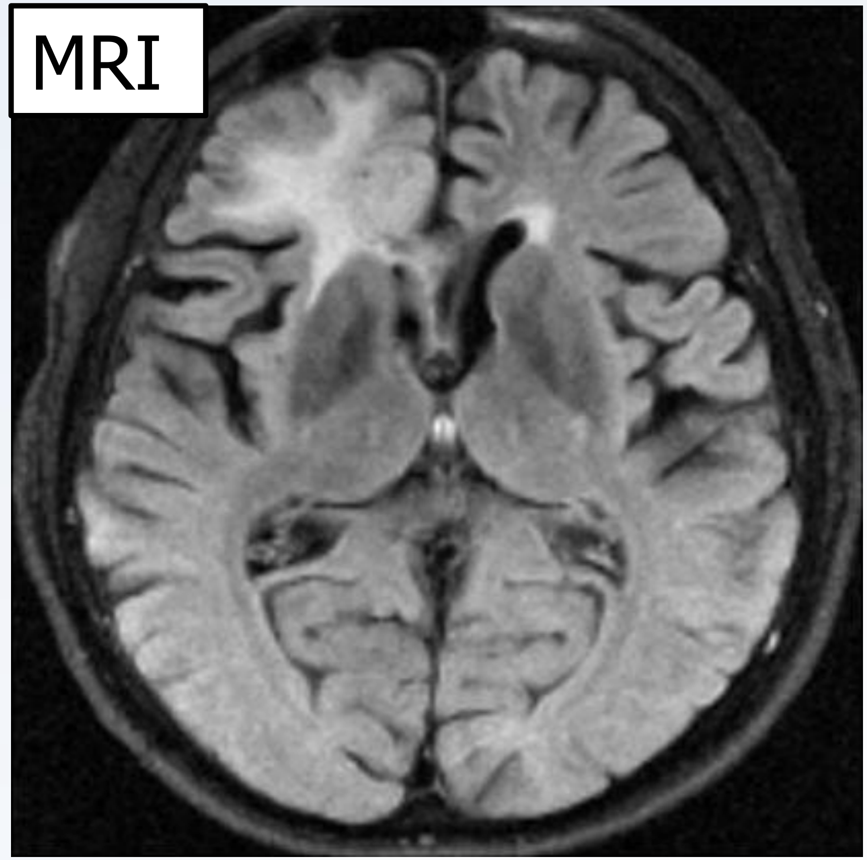
Postdoctoral Fellow
Magnetic Resonance Spectroscopy Unit
McConnell Brain Imaging Centre
Montreal Neurological Institute
McGill University

Structural Image Pre-processing: Introduction

- Structural image processing and structural image **pre**-processing
  - Pre-processing depends on study setting, later analysis,
  - It can have significant impact on entire analysis
  - Difficult to calibrate or develop optimized approach
- Examples of structural image pre-processing

MRI is the modality of choice for structural imaging

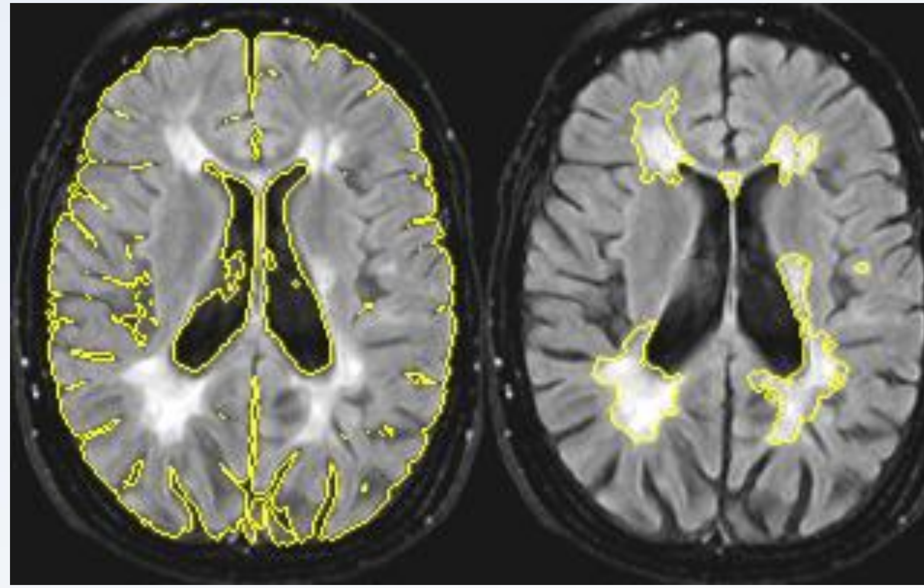


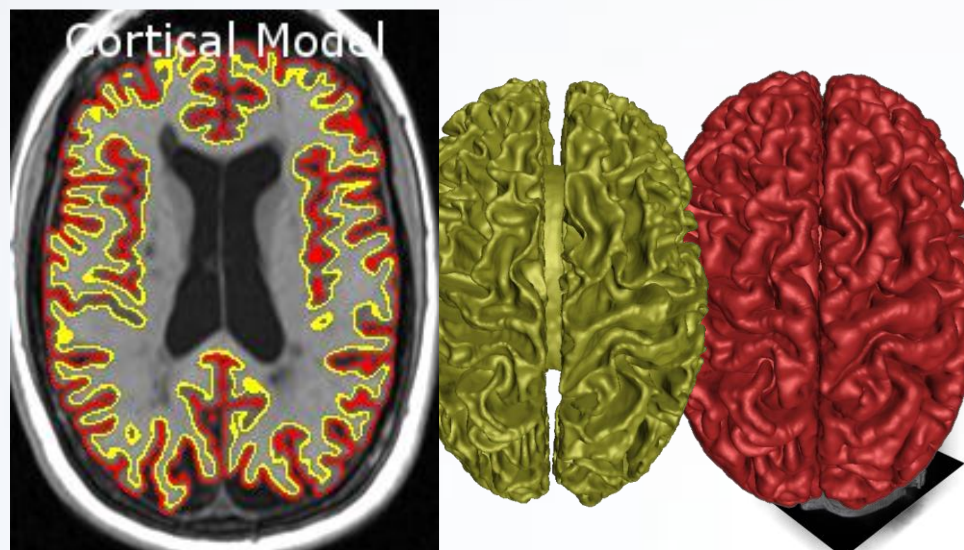


Boss et al 2010 JNM

What is Structural Image P~~re~~processing

- Analysis **before** ‘structural image processing’
- To clean up images
  - Satisfies the assumption made by structural processing methods
  - Brain segmentation
  - Multiple Sclerosis lesion segmentation
  - Cortical surface extraction





Nakamura et al NeuroImage 2011

Pre-processing is often overlooked

MRI protocol

Automated quantification was performed on T_1-weighted MR images of the brain obtained from a 1.5-T Philips Gyroscan ACS II (Philips Medical Systems, Best, The Netherlands) with TR = 35 ms, TE = 11 ms, axial contiguous 3 mm slices, and a 256 × 256 image matrix. Images were corrected for intensity nonuniformity using the nonparametric nonuniform intensity normalization algorithm N3 (Sled et al., 1998).

2.2. MRI scan processing

Images were corrected for intensity inhomogeneity using the N3 algorithm (www.bic.mni.mcgill.ca/software/N3/) (Sled et al., 1998), and the images were segmented into brain/nonbrain using a semiautomated technique (MIDAS) (Freeborough et al., 1997). Two methods for quantifying rates of global gray matter atrophy and 2 methods for quantifying rates of whole brain atrophy were subsequently applied over 6- and 12-month intervals as follows.

2.2.1. Segmentation and subtraction of serial GM volumes

All images and brain regions were transformed into

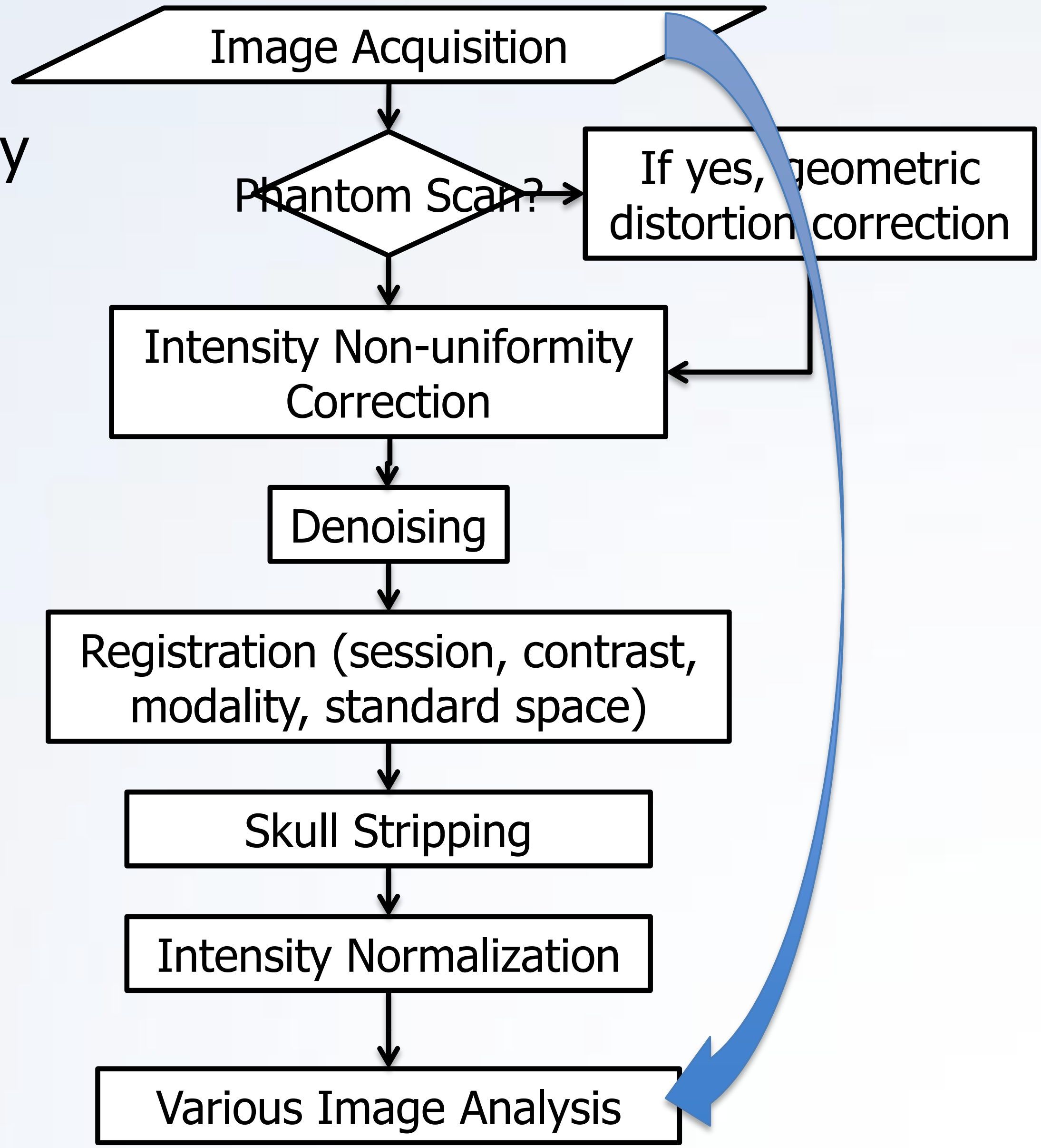
The overall flow chart, including pre-processing steps and gray matter segmentation steps, is shown in Fig. 1. Prior to GM segmentation, the brain is isolated from non-brain tissues in fluid attenuated inversion recovery (FLAIR) images using a fully automated knowledge-based segmentation method, as previously described (Fisher et al., 1997). The outer contour of the brain, a smoothed surface that includes the ventricles and other cerebrospinal fluid surrounding the brain, is also determined in this step, and the total brain parenchymal volume and volume within the outer contour are determined. In images of MS patients, T2 hyperintense white matter lesions are segmented in the FLAIR images using a modified version of the iterated conditional modes algorithm (Besag, 1986).

T1-weighted images, and/or any other images to be used in the tissue classification step, are pre-processed by anisotropic diffusion filtering (ADF) (Perona and Malik, 1990), N3 intensity variation correction (Sled et al., 1998), and inter-slice intensity correction programs. The inter-slice intensity correction algorithm estimates and reduces the loss of signal due to intensity drop-off in the superior and inferior slices. A single multiplication factor is estimated for each slice by measuring the mode of the pixel-by-pixel ratios between contiguous slices within the brain. FLAIR and T1-weighted images are co-registered using a normalized mutual information algorithm (Pluim et al., 2003) with downhill simplex optimization (Press et al., 2002). Patient motion between 2 interleaved sets is corrected using the same normalized mutual information registration algorithm by separating, registering, and re-combining the two interleaved image sets.

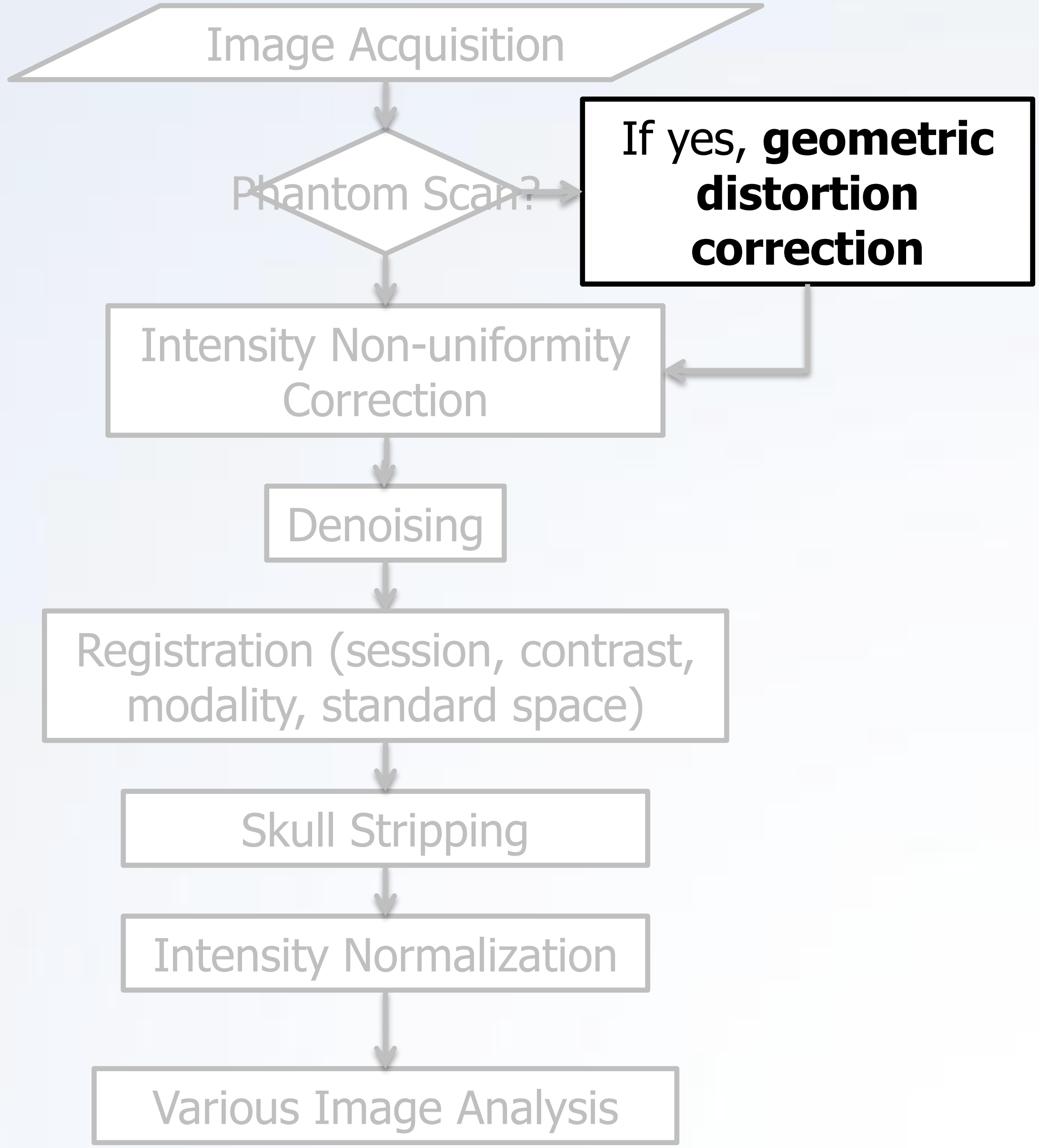
After preprocessing, voxels within the brain mask are classified

Structural Image Preprocessing

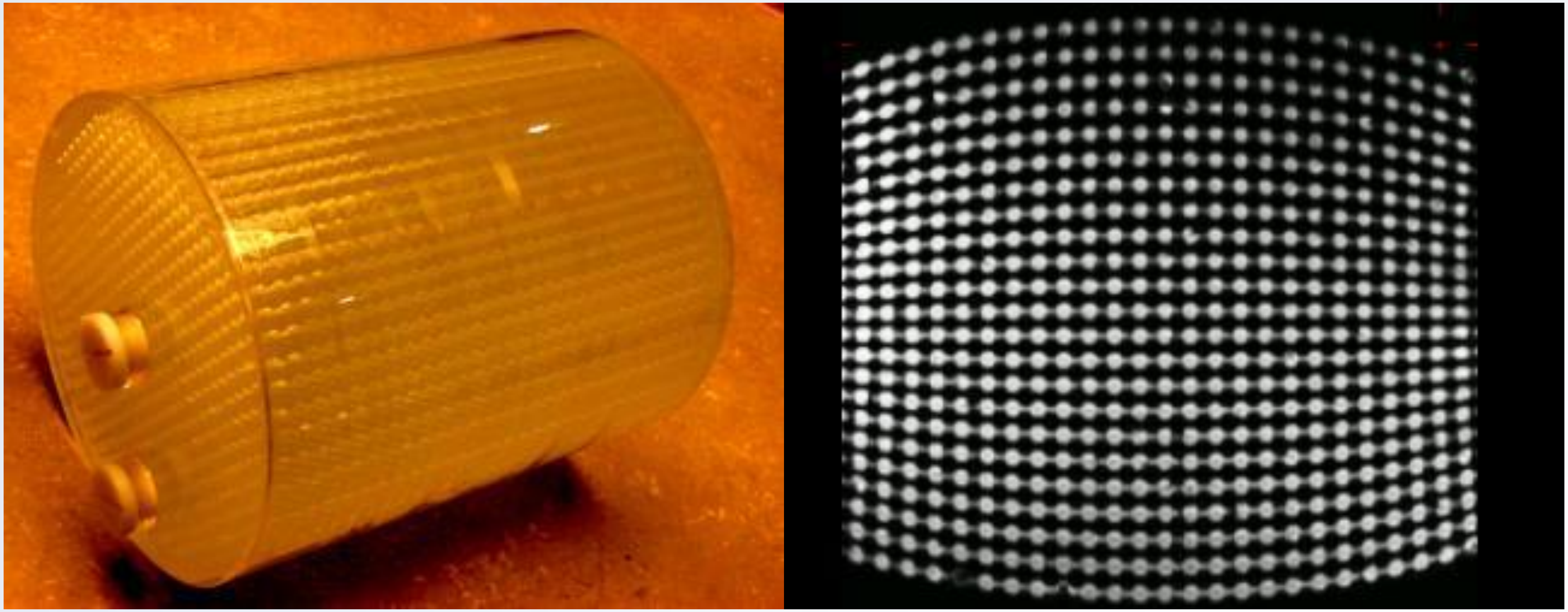
1. Geometric distortion
2. Intensity non-uniformity
3. Noise reduction
4. Motion correction
5. Skull stripping
6. Intensity normalization



Structural Image Preprocessing



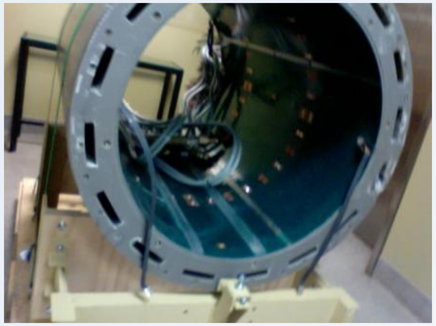
Geometric Distortion



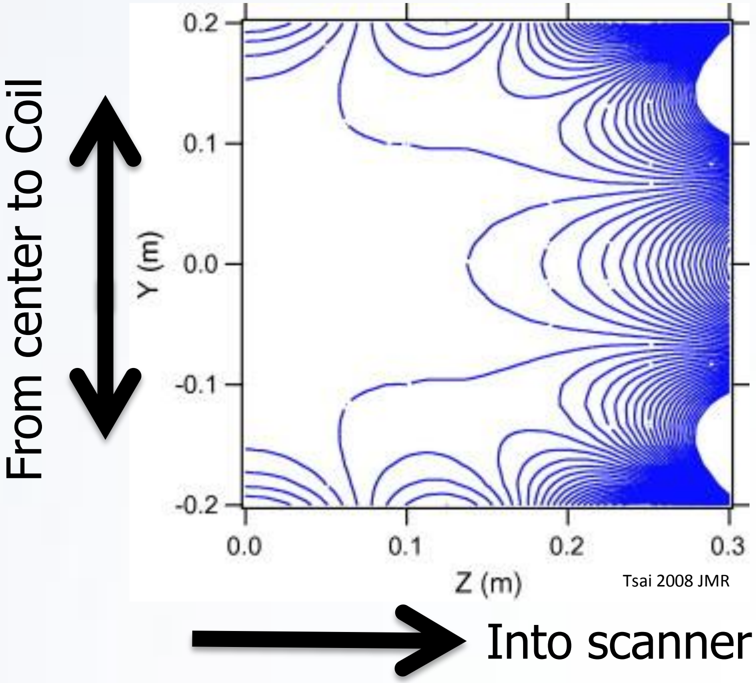
Jovich et al. 2006 NeuroImage

Geometric distortion

- What causes it?
  - Nonlinear fields
    - Gradient field
    - Magnetic field
    - Others (susceptibility, chemical shift, etc)



B_0 Magnetic Field as function of Distance from Center of Magnet



Geometric distortion

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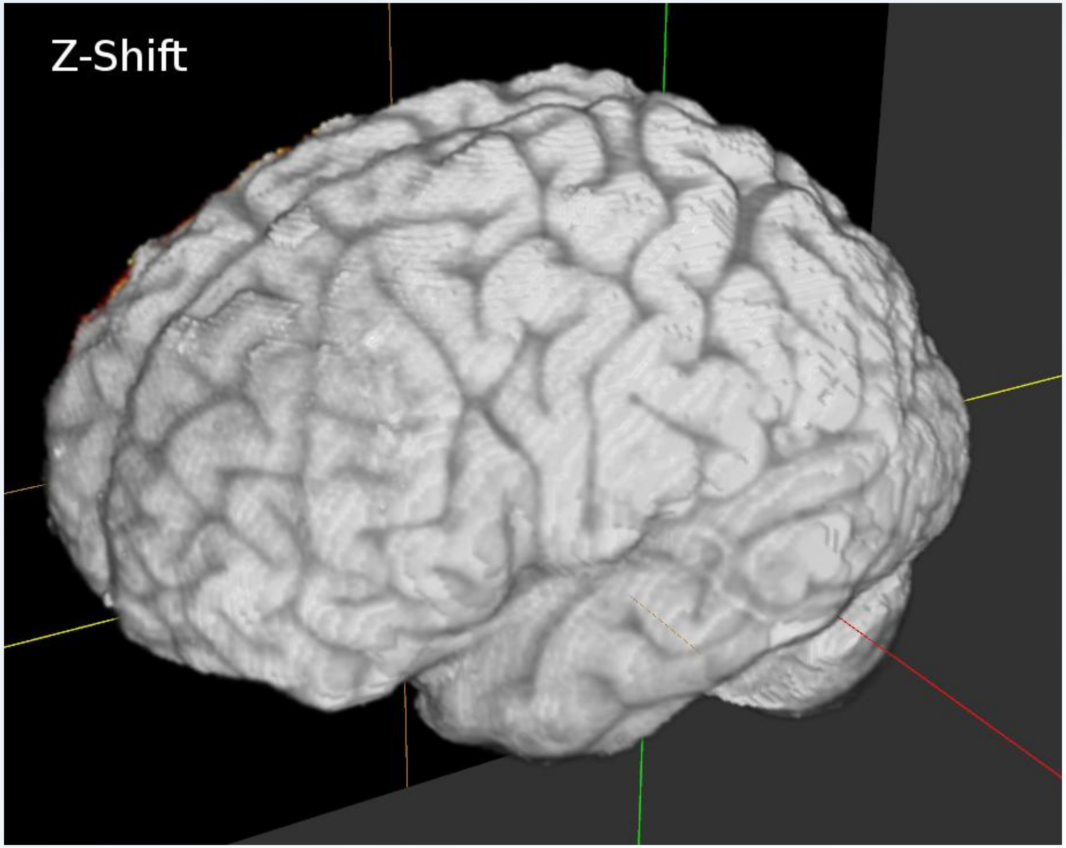

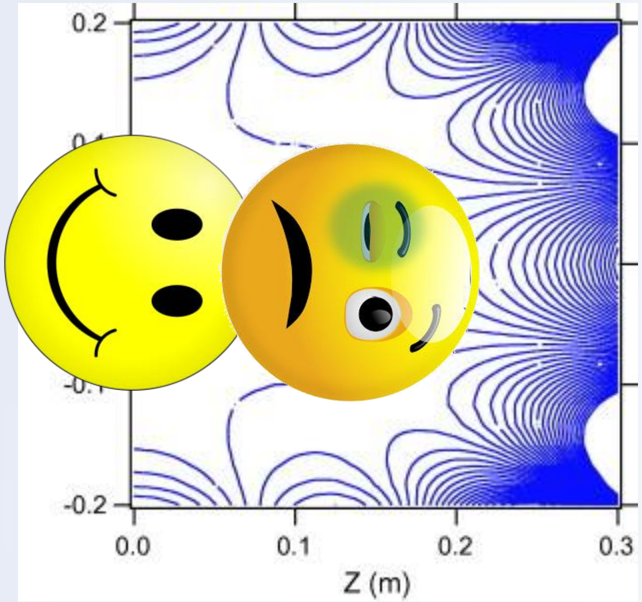

Geometric distortion

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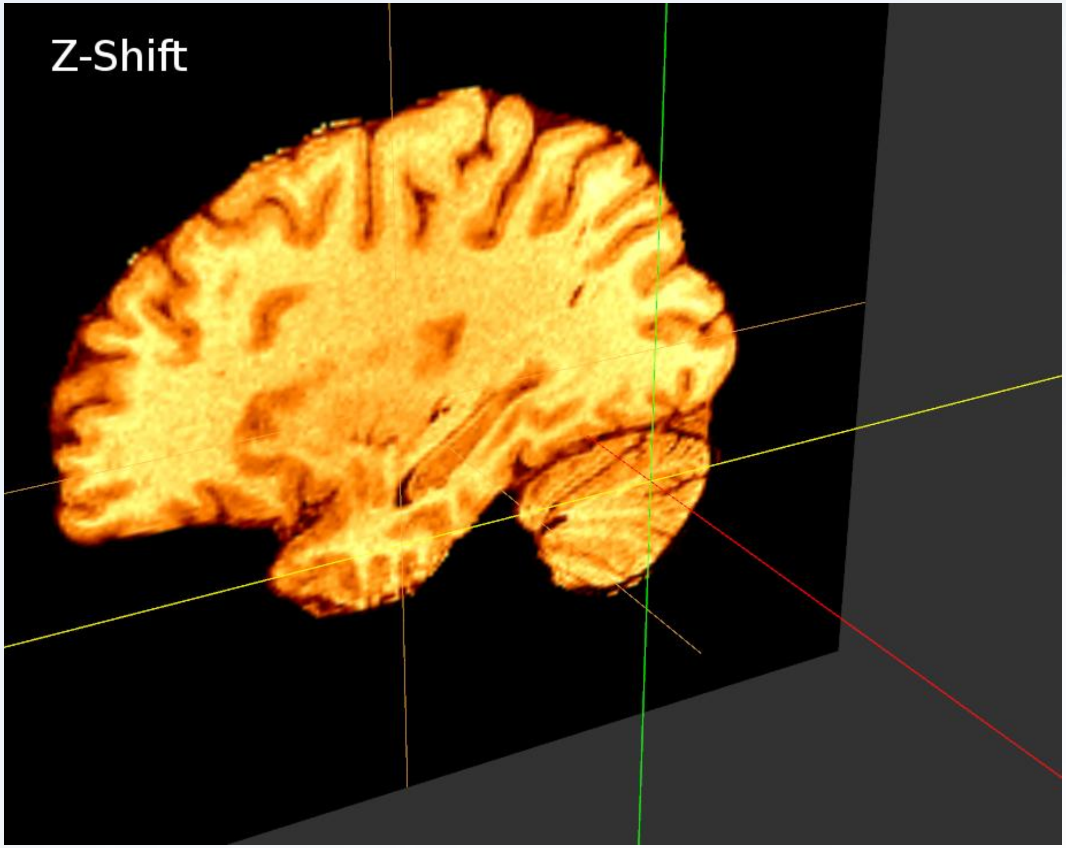
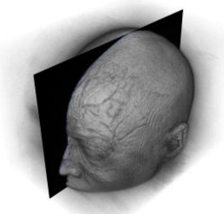
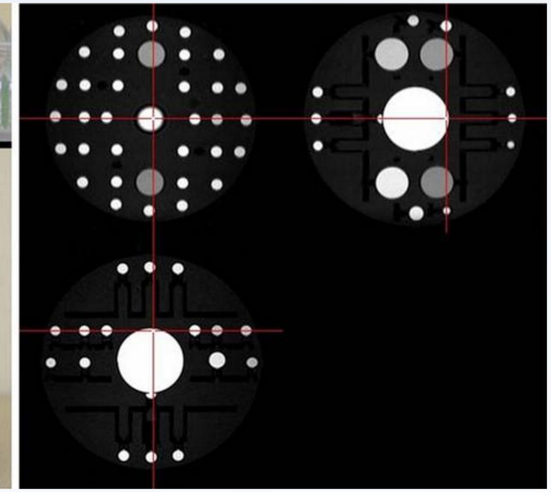
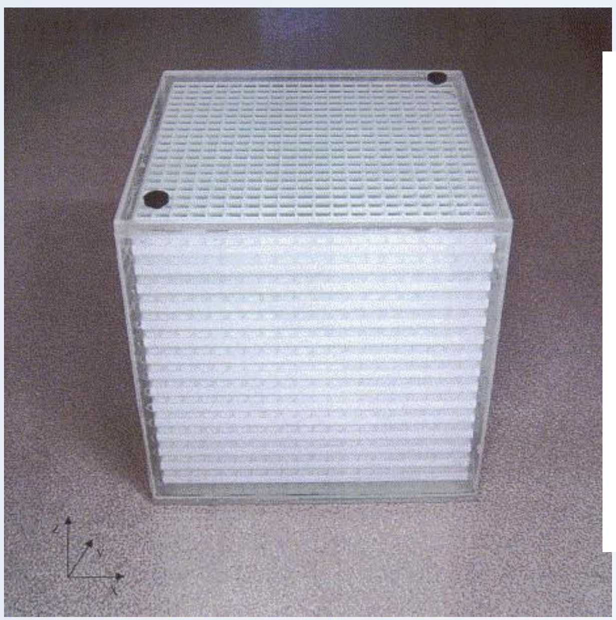


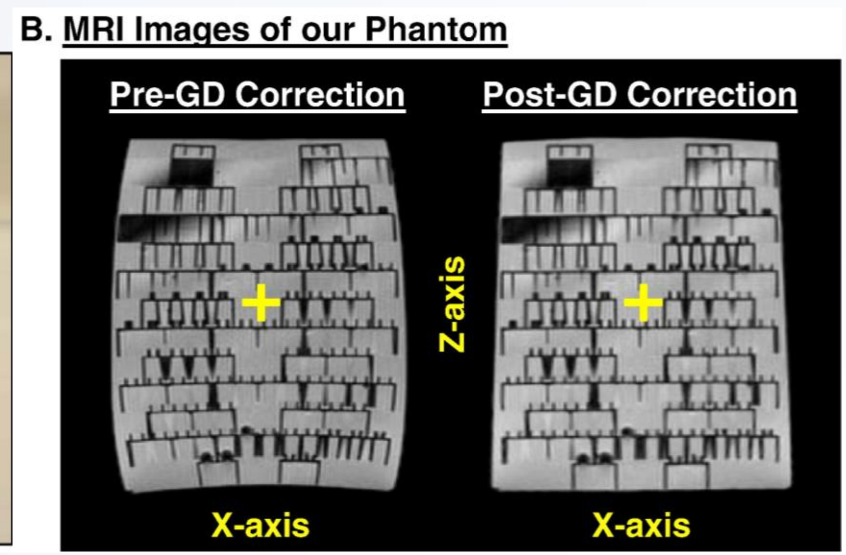


Correction of geometric distortion



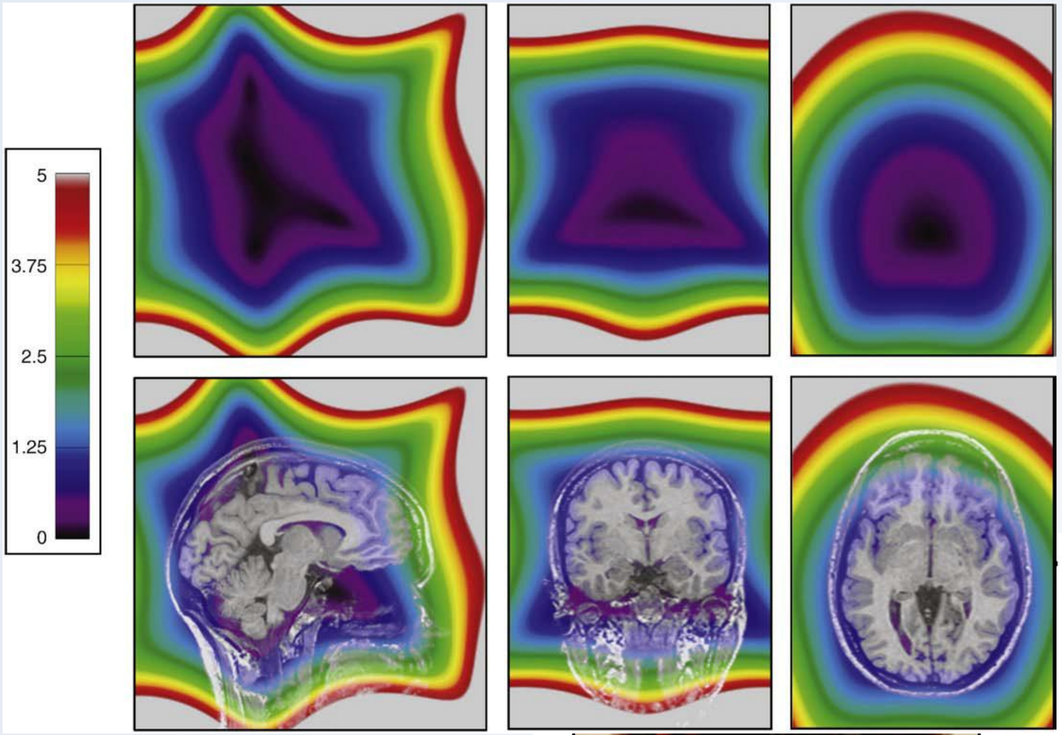
- Phantoms
  - Standard phantom
  - ADNI phantom
  - Lego phantom

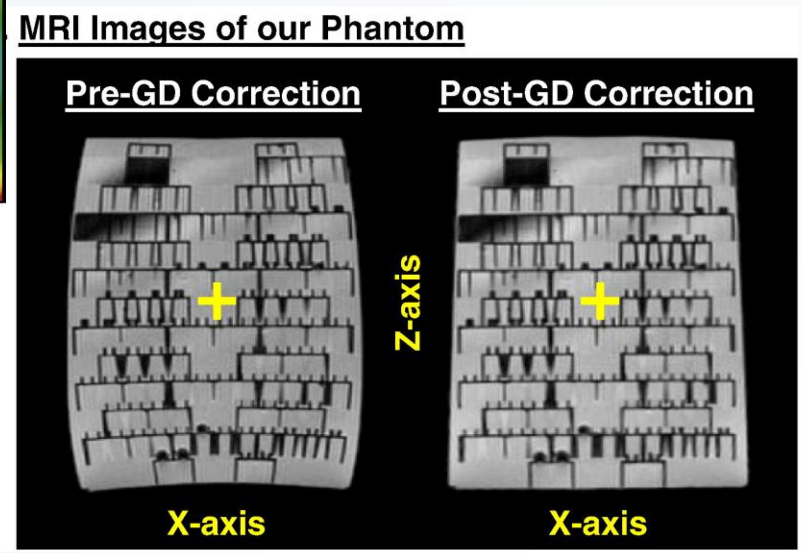




Wang 2004 MRI; Gunter 2009 Med Phys; Caramanos et al. 2010 NeuroImage

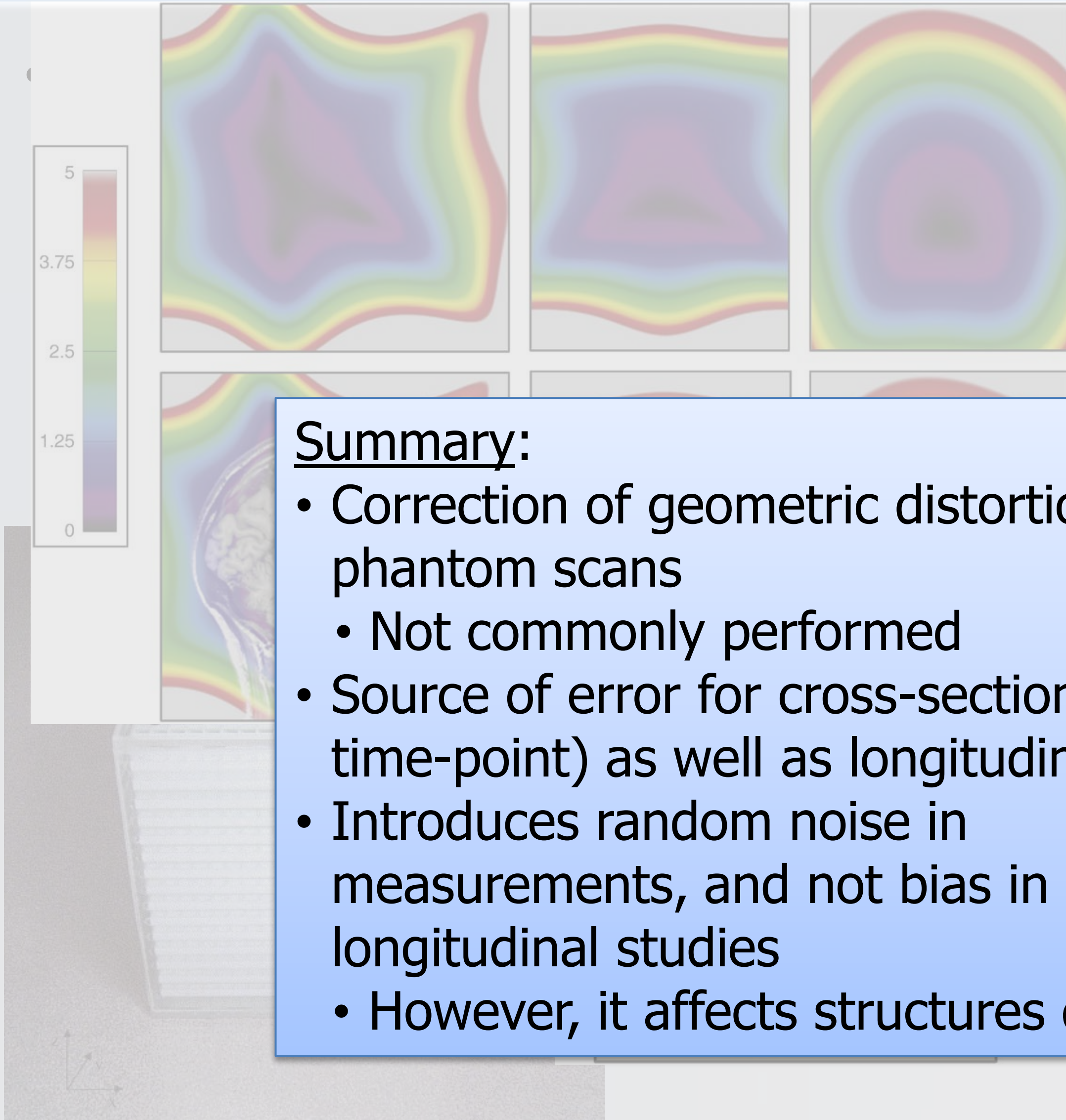
Correction of geometric distortion

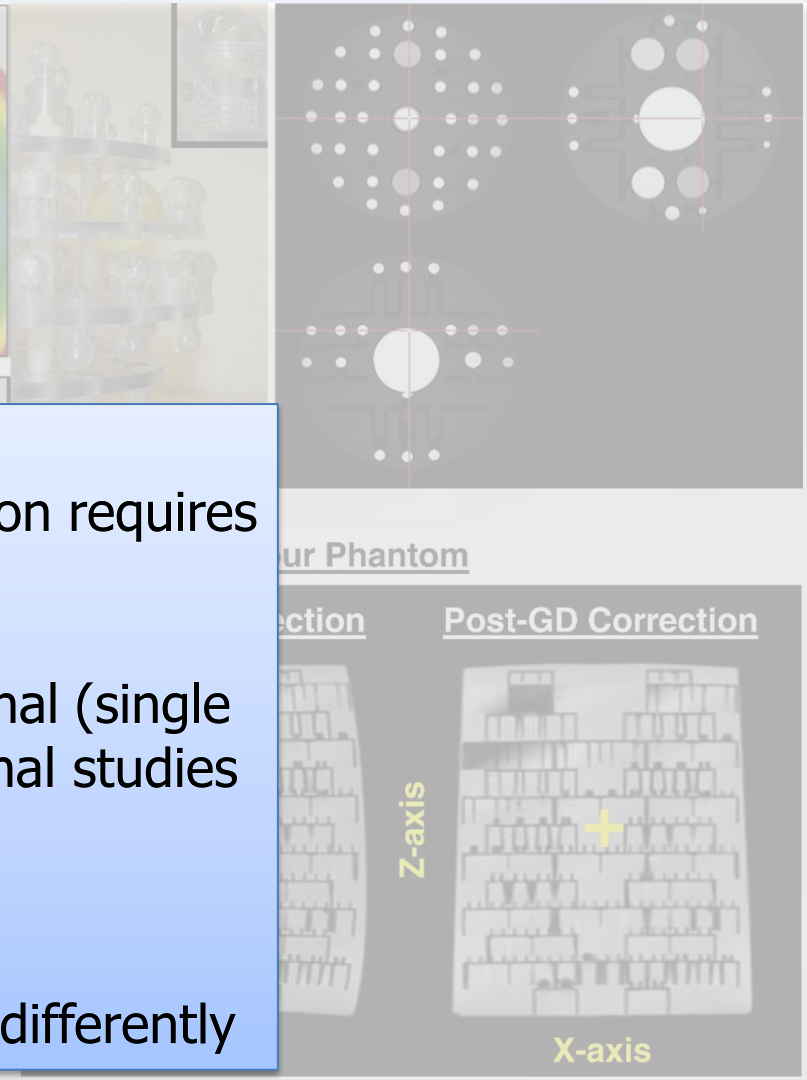




Caramanos et al. 2010 NeuroImage

Correction of geometric distortion

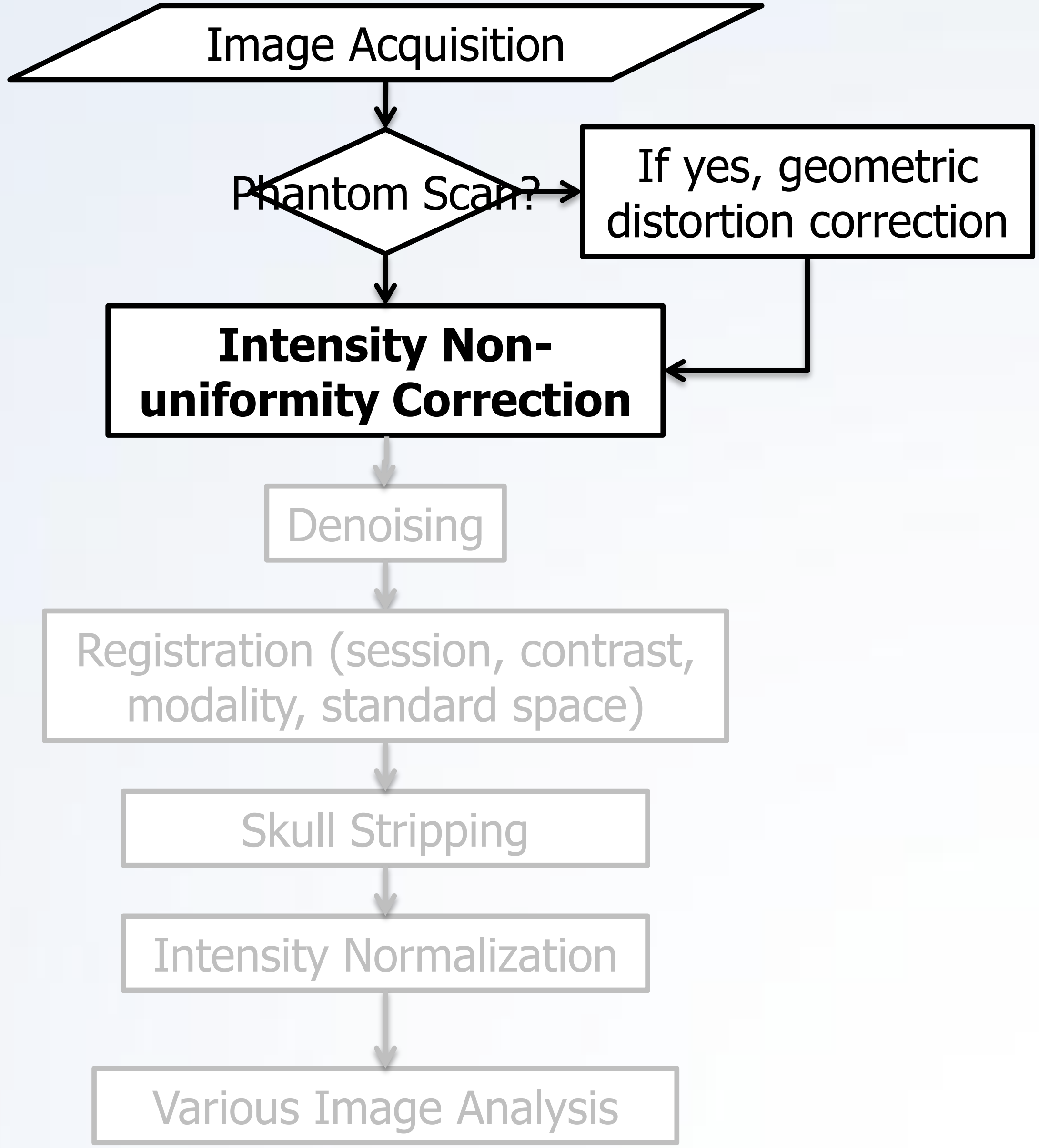




Summary:

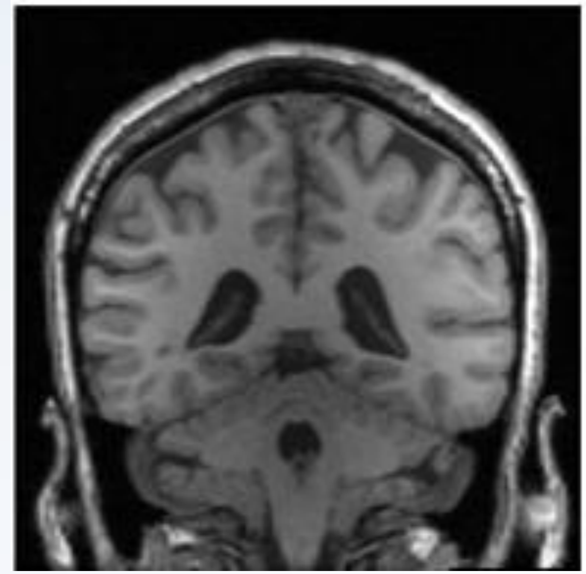
- Correction of geometric distortion requires phantom scans
  - Not commonly performed
- Source of error for cross-sectional (single time-point) as well as longitudinal studies
- Introduces random noise in measurements, and not bias in longitudinal studies
  - However, it affects structures differently

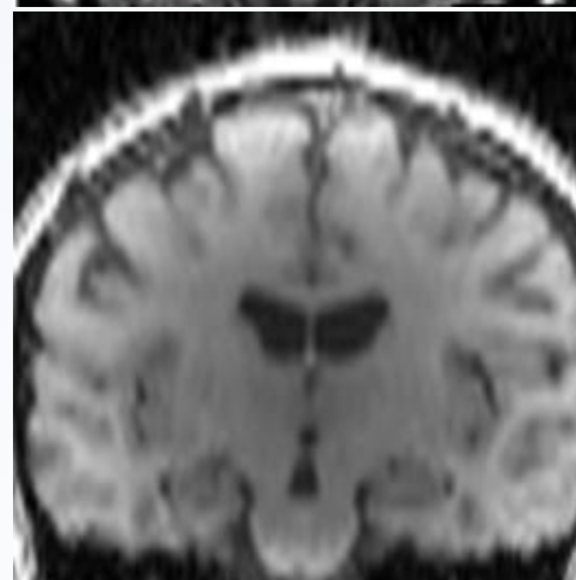
Structural Image Preprocessing



Intensity non-uniformity

- What is it?
- What causes it?
  - B_0 inhomogeneity (main magnet)
  - Gradient inhomogeneity
  - Radiofrequency inhomogeneity
  - Amplifiers
  - Analog-to-Digital Converter
- Which images are affected?
  - All
- How do we correct intensity non-uniformity
  - Estimation of bias field





Intensity non-uniformity

- What is it?
- Wh
  - E
  - R
  - Gradient inho
  - Amplifiers
  - ADC

A Nonparametric Method for Automatic Correction of Intensity Nonuniformity in MRI Data

John G. Sled,* Alex P. Zijdenbos, *Member, IEEE*, and Alan C. Evans

J. G. Sled is with the McConnell Brain Imaging Centre, Montréal Neurological Institute and McGill University, 3801 University Street, Montréal, P.Q., H3A 2B4 Canada (e-mail: jgsled@bic.mni.mcgill.ca).

A. P. Zijdenbos and A. C. Evans are with the McConnell Brain Imaging Centre, Montréal Neurological Institute and McGill University, Montrèal, P.Q., H3A 2B4 Canada

Publisher Item Identifier S 0278-0062(98)03151-6.

A nonparametric method for automatic correction of intensity nonuniformity in MRI data

JG **Sled**, AP Zijdenbos, AC Evans - Medical Imaging, IEEE …, **1998** - ieeexplore.ieee.org

Abstract A novel approach to correcting for intensity nonuniformity in magnetic resonance (MR) data is described that achieves high performance without requiring a model of the tissue classes present. The method has the advantage that it can be applied at an early ...

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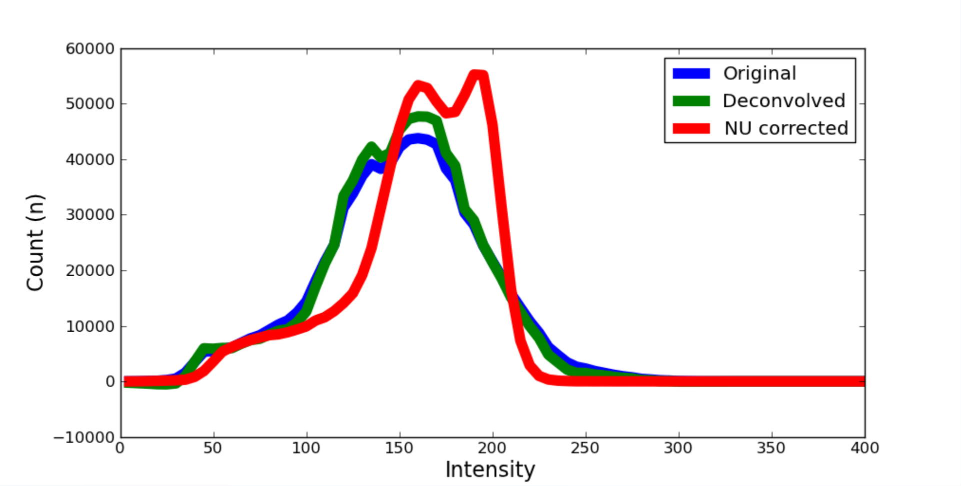
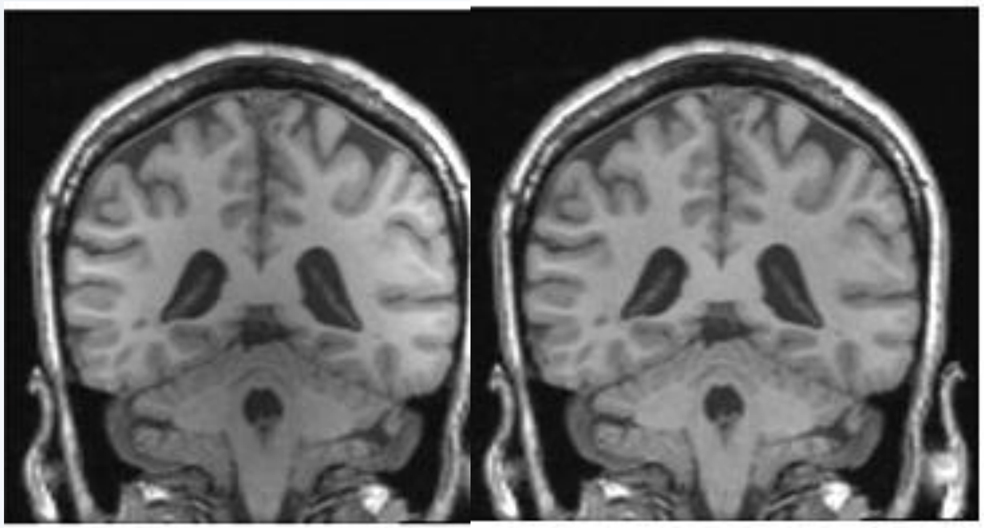
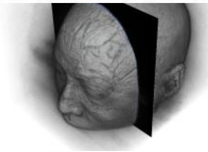
- N3

N3 Correction

- Original MRI
- Log-transformation
- Create histogram
- Deconvolution of histogram
- Estimate bias field
  - From difference between original and deconvolved histograms (conceptually)
  - Spline smoothing
- Repeat until change is small
- Remove bias and Exp-transformation





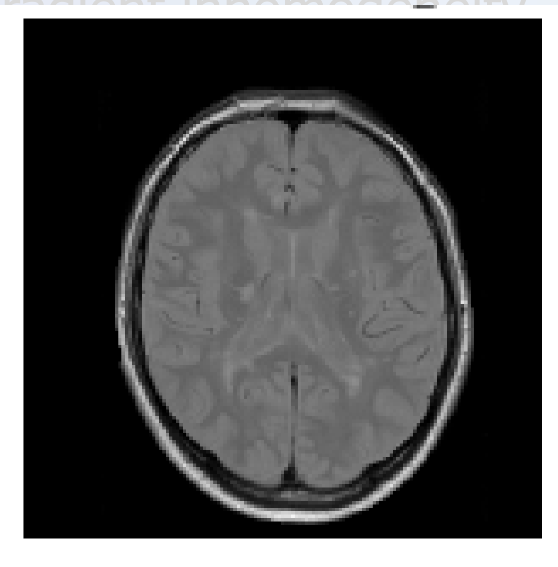


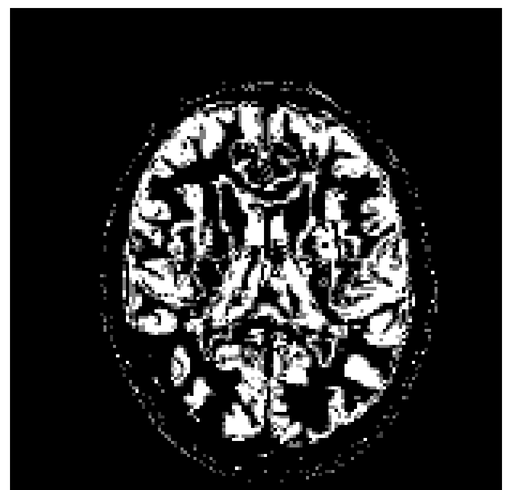
Intensity non-uniformity


IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 19, NO. 3, MARCH 2000, P153-165

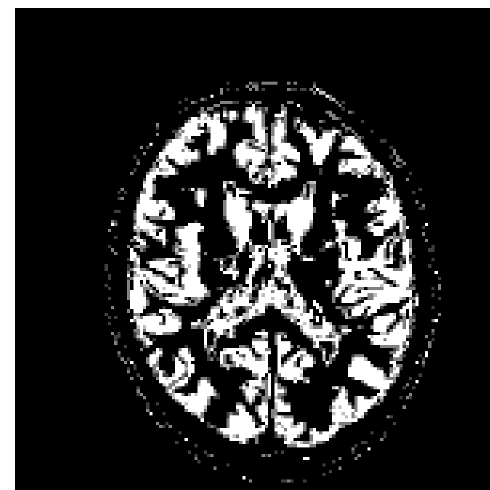
Parametric estimate of intensity inhomogeneities applied to MRI

Martin Styner, Christian Brechbühler , Gábor Székely and Guido Gerig





Segmentation from Uncorrected Volume



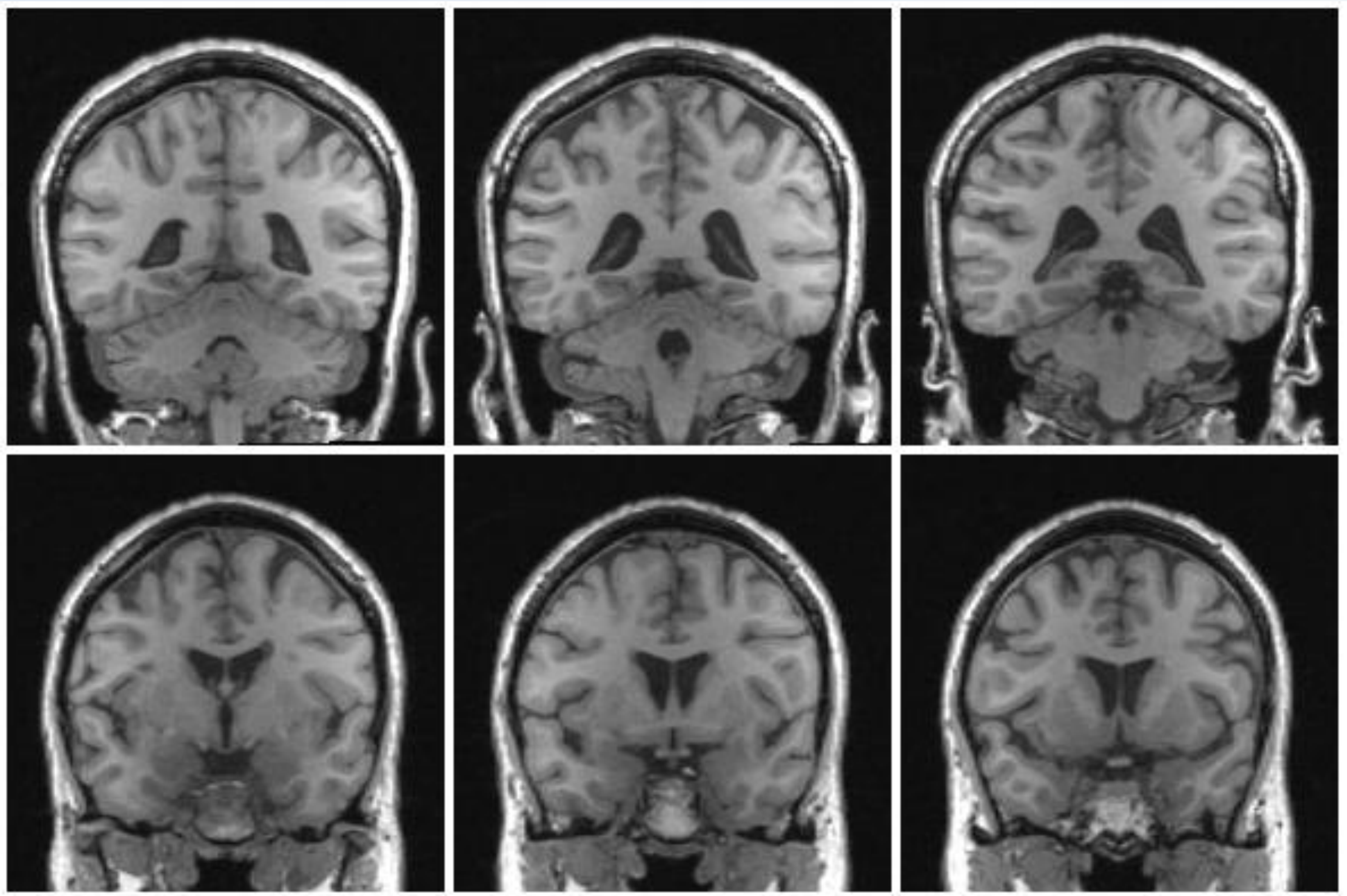
Segmentation from Corrected Volume

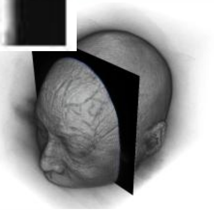
- How
  nor
  - N3
  - PABIC by Styner

Intensity non-uniformity

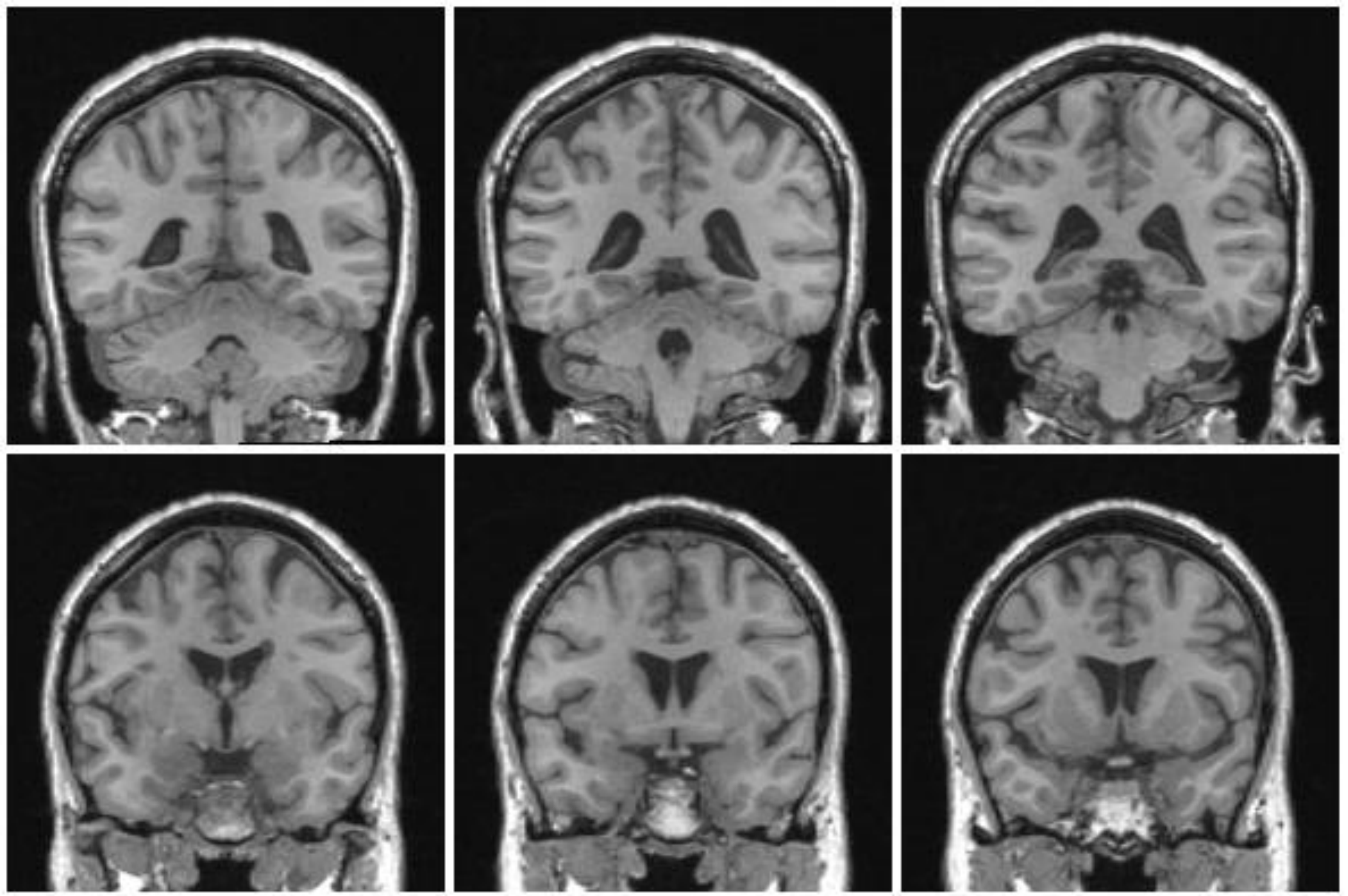
- What is it?
- What causes it?
  - B_0 inhomogeneity
  - RF inhomogeneity
  - Gradient inhomogeneity
  - Amplifiers
  - ADC
- Which images are affected?
  - All
- How do we correct intensity non-uniformity
  - N3
  - PABIC by Styner
- Intensity non-uniformity can be estimated during segmentation
  - FAST (SIENAX) in FSL
  - Segment in SPM

Intensity non-uniformity

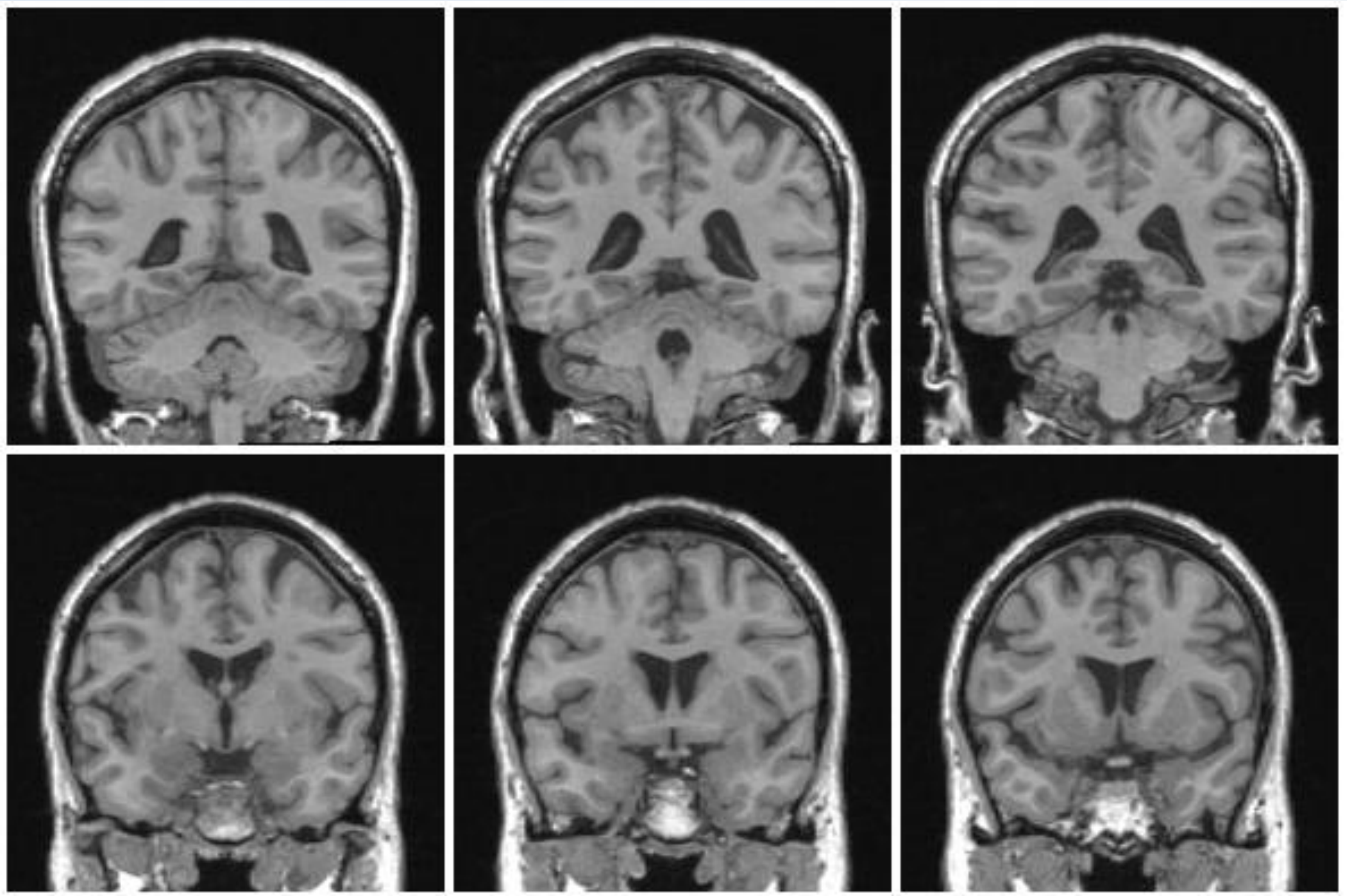


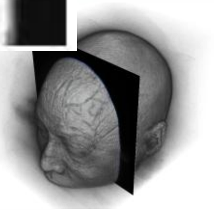


Intensity non-uniformity

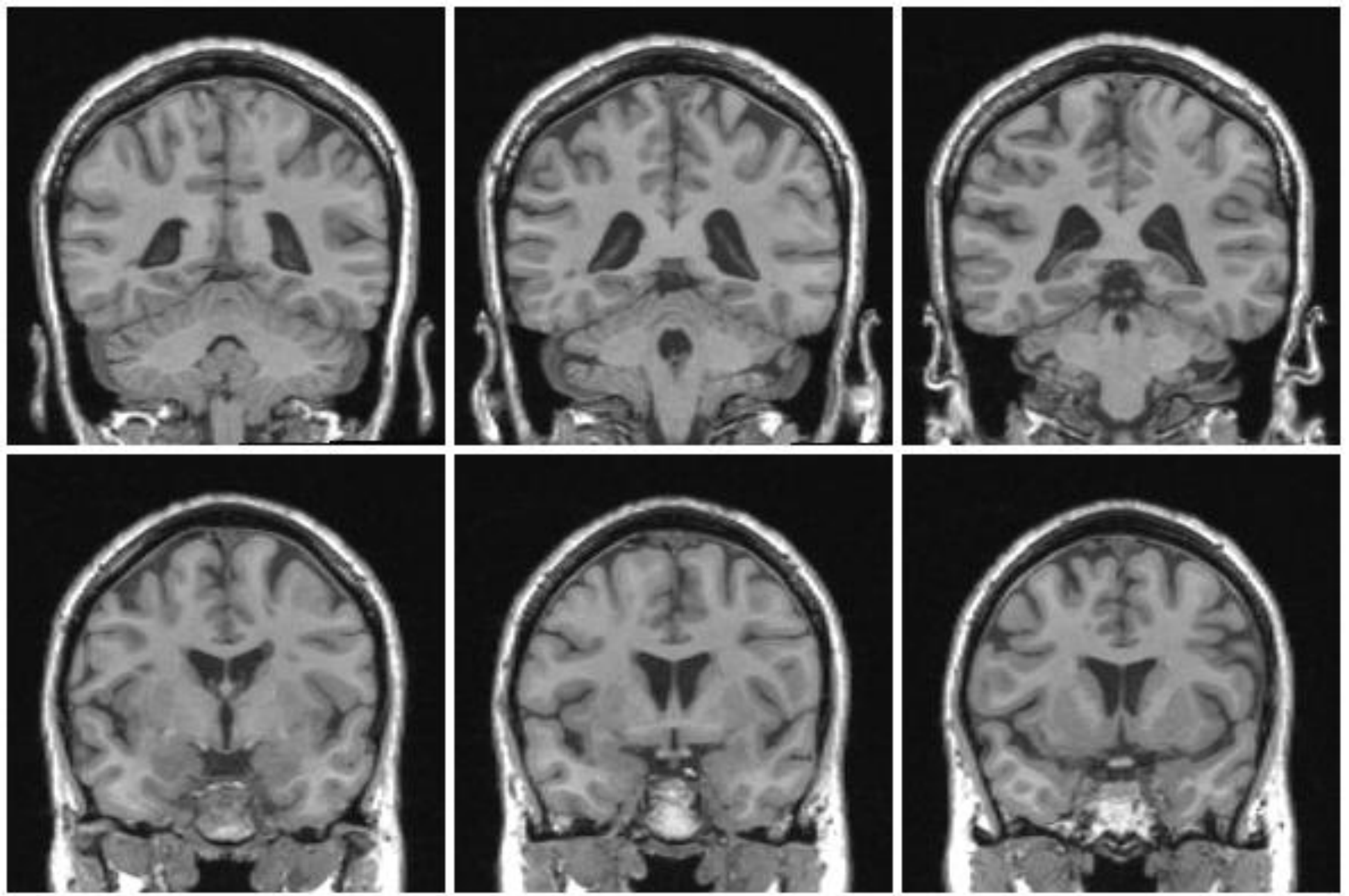


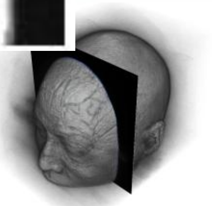
Intensity non-uniformity





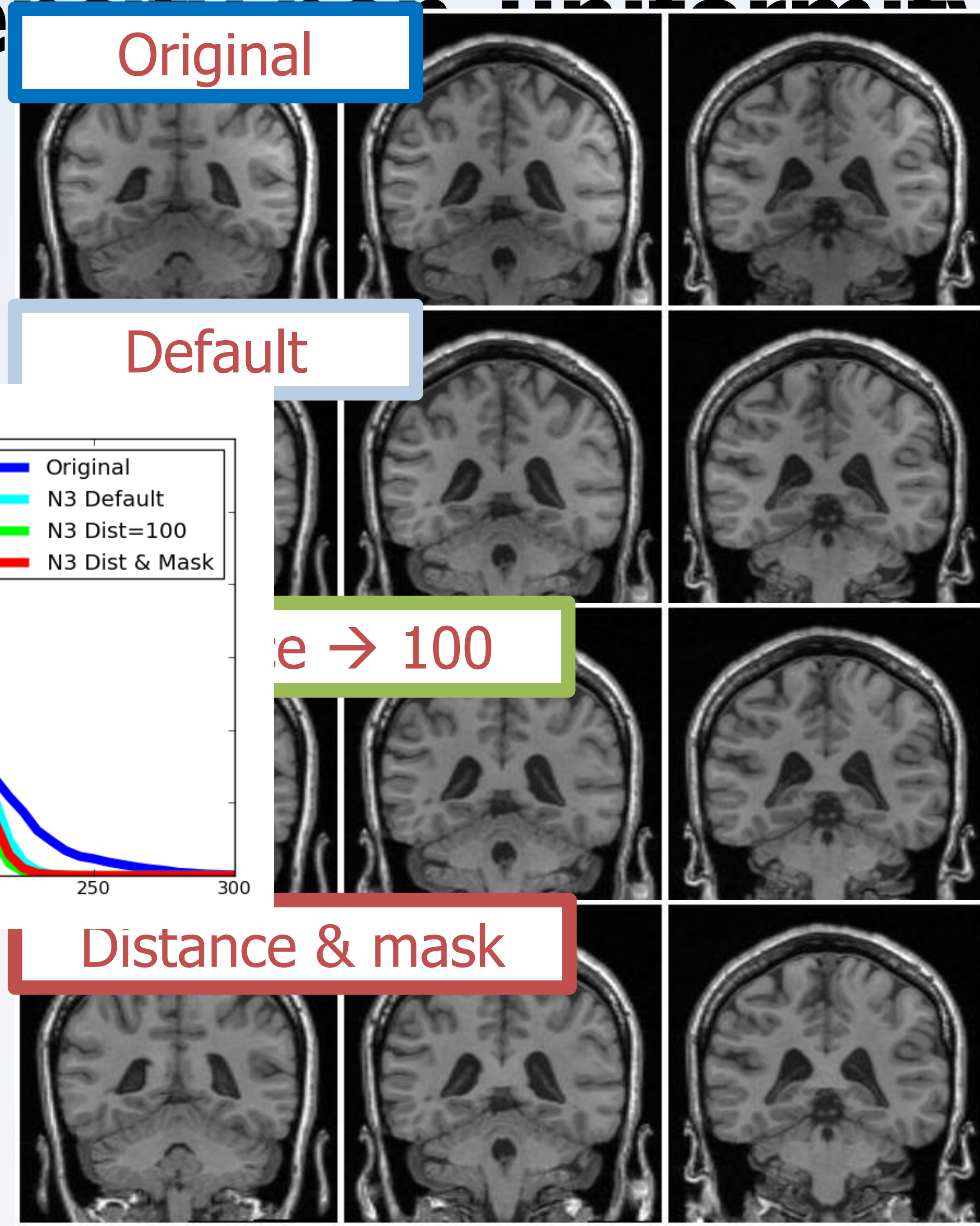
Intensity non-uniformity

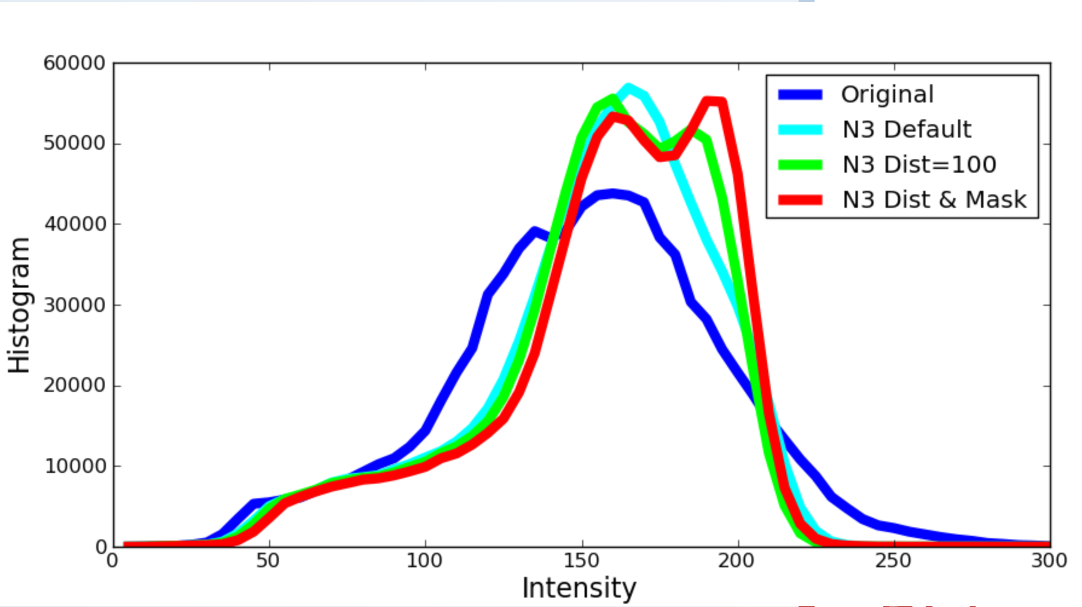




Intensity non-uniformity

- N3 method

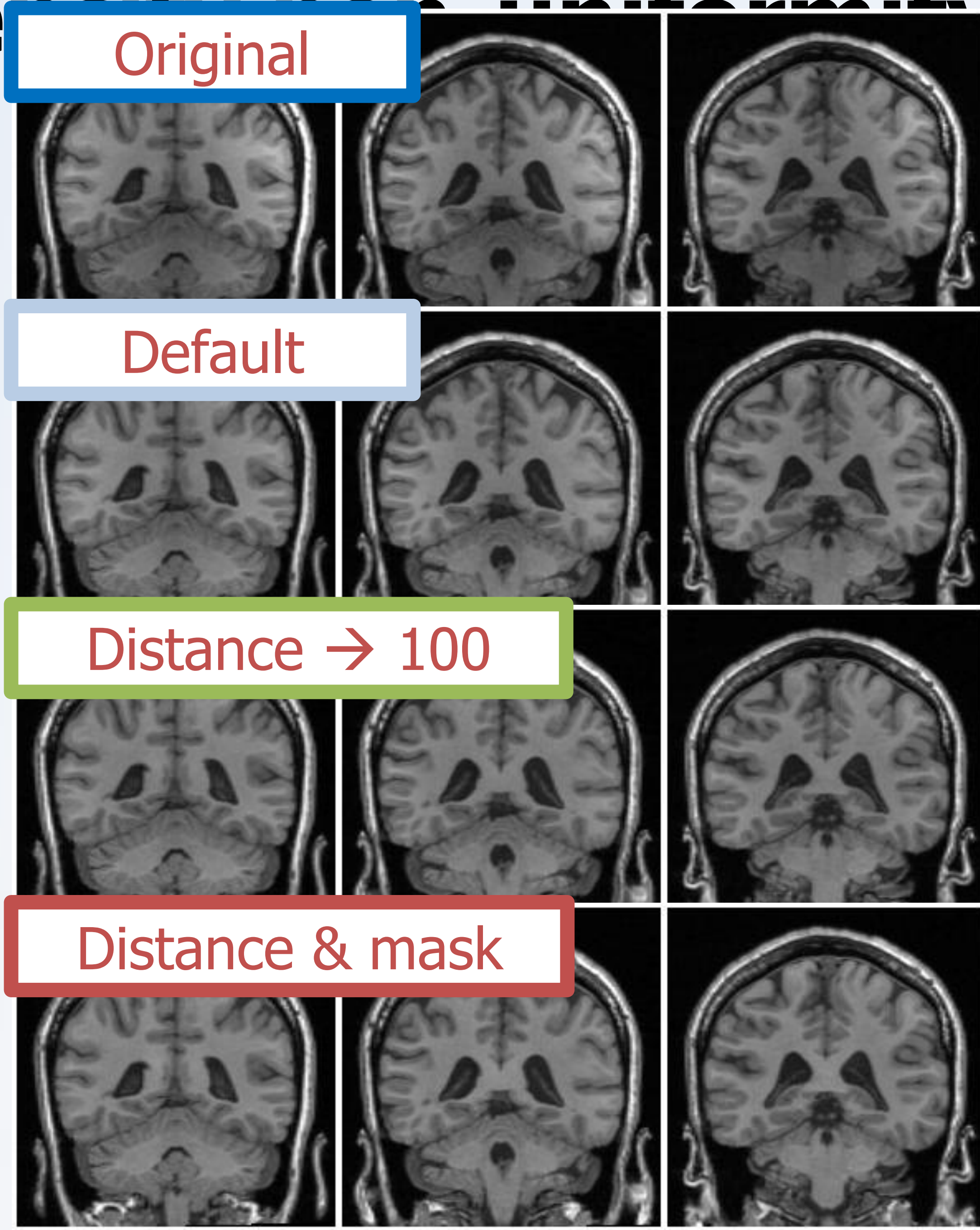




Intensity non-uniformity

- N3 method

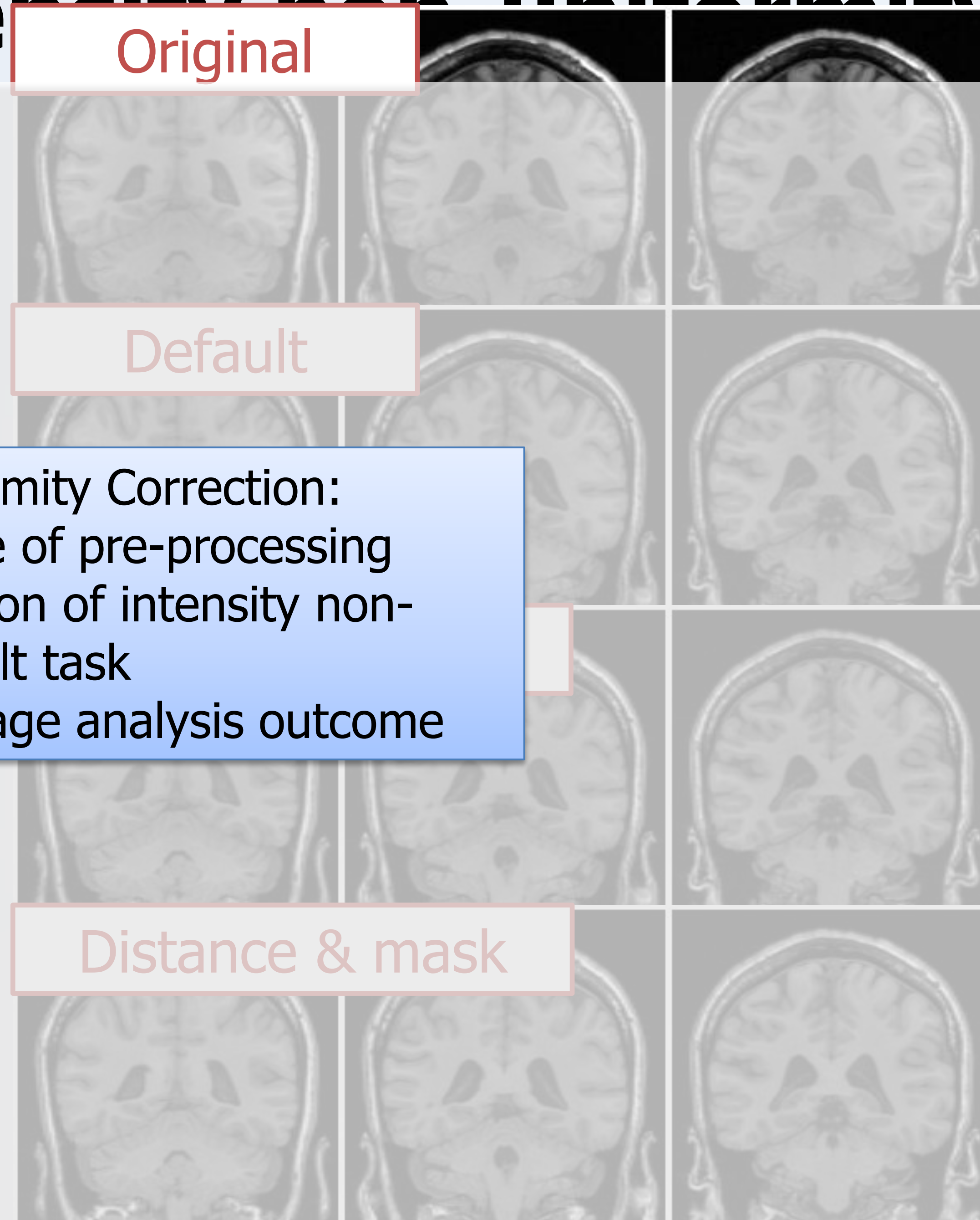
- Optimized calibration of intensity non-uniformity correction is not easy
  - Often overlooked
  - Directly affects image analysis outcome



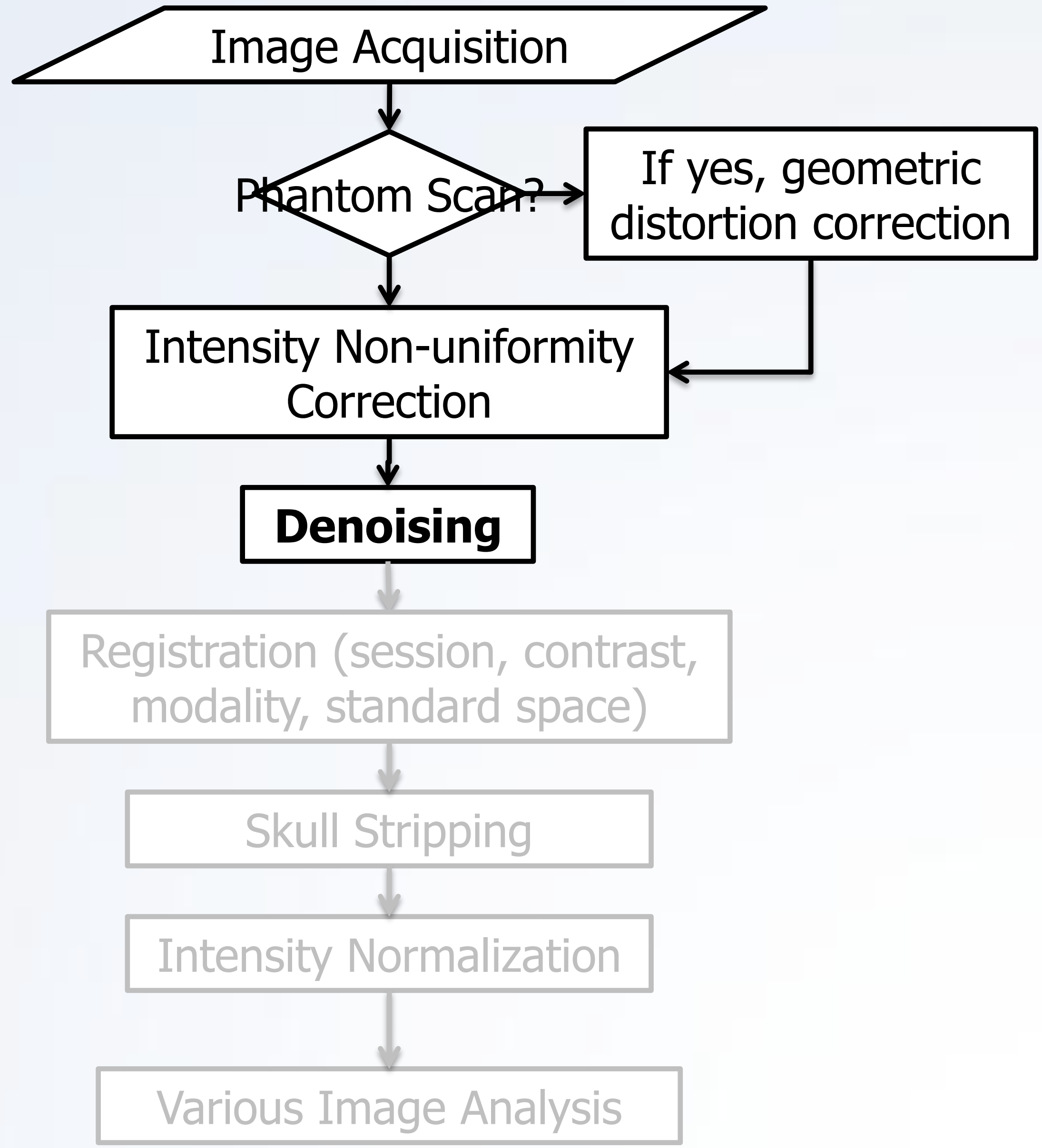
Intensity non-uniformity

- N3 method
- Optimized calibration of intensity non-unifor... not ea...
  - Oft...
  - Dire... analysis outcome

Intensity Non-Uniformity Correction:
- Most common type of pre-processing
- Optimized calibration of intensity non-uniformity a difficult task
- Directly affects image analysis outcome

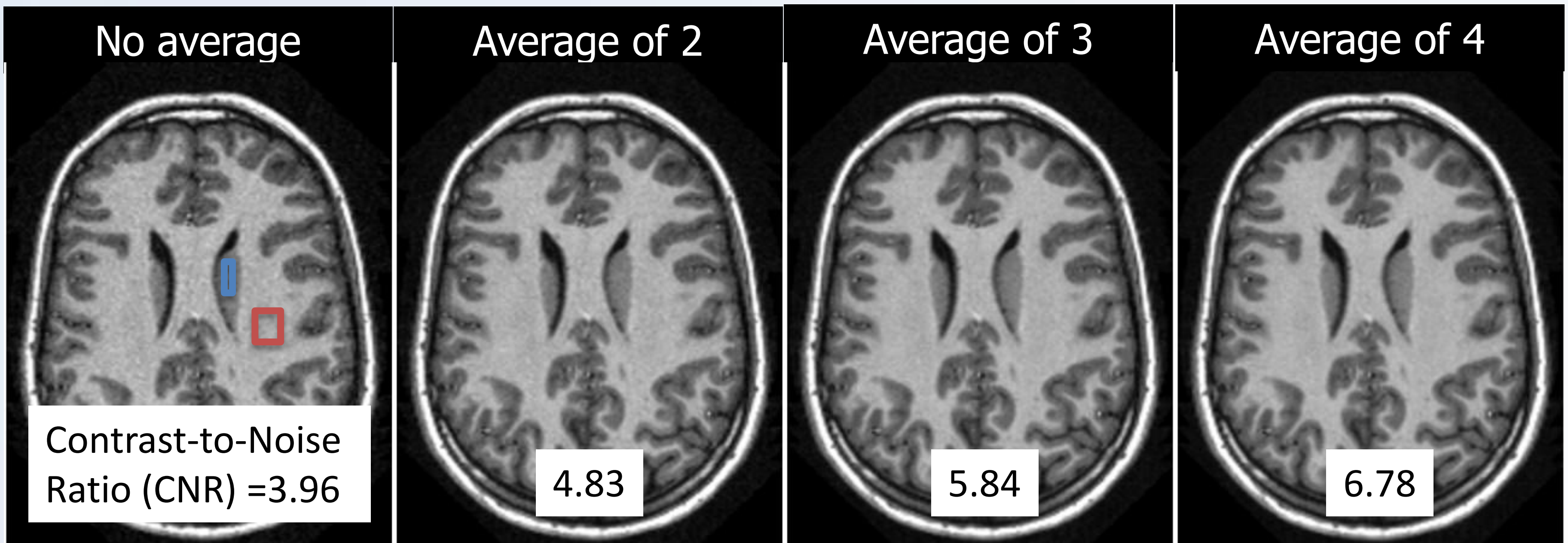


Structural Image Preprocessing



Noise Reduction

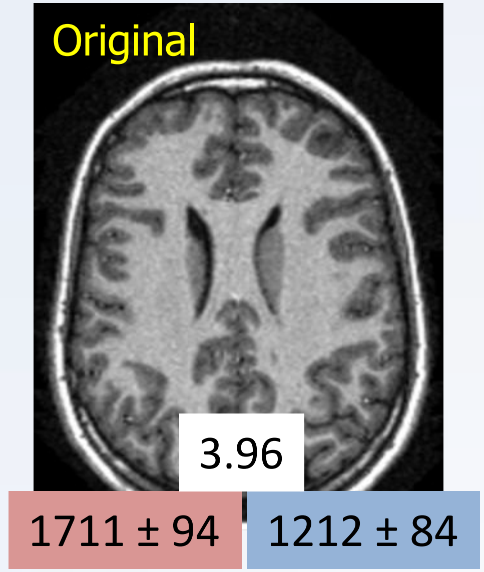
- Acquisition
  - Signal averaging

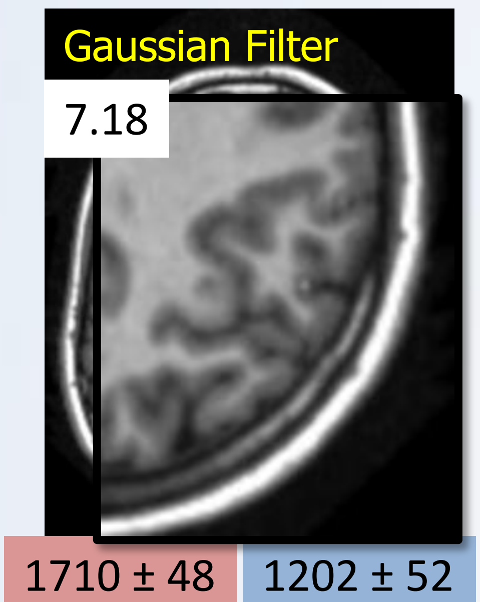


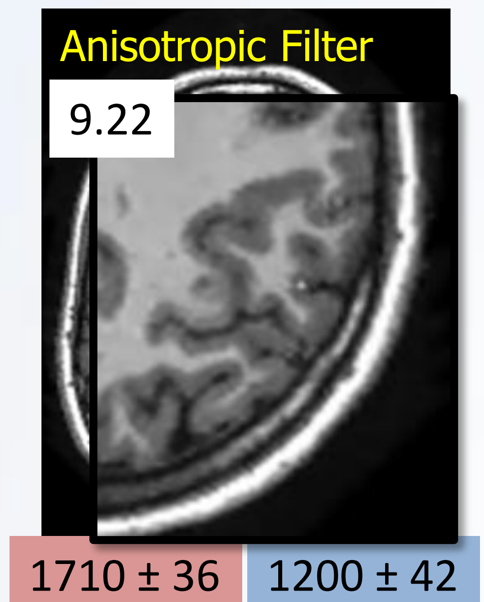
1711 ± 94	1705 ± 77	1704 ± 62	1705 ± 52
1212 ± 84	1212 ± 67	1208 ± 58	1211 ± 51

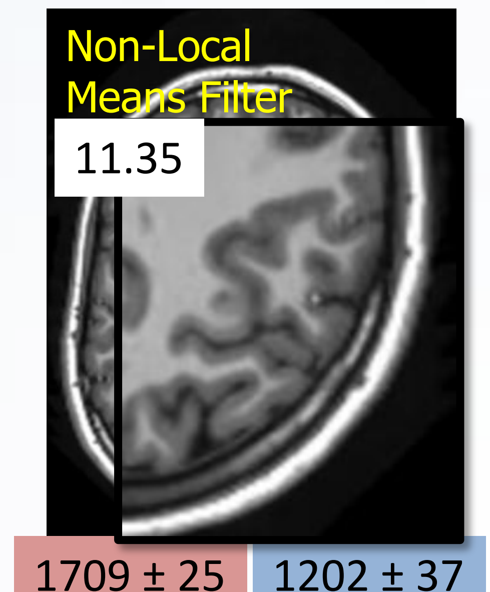
Noise Reduction

- Acquisition
  - Signal averaging
- Image processing
  - Blurring
  - Anisotropic blurring
  - Non-local means filter





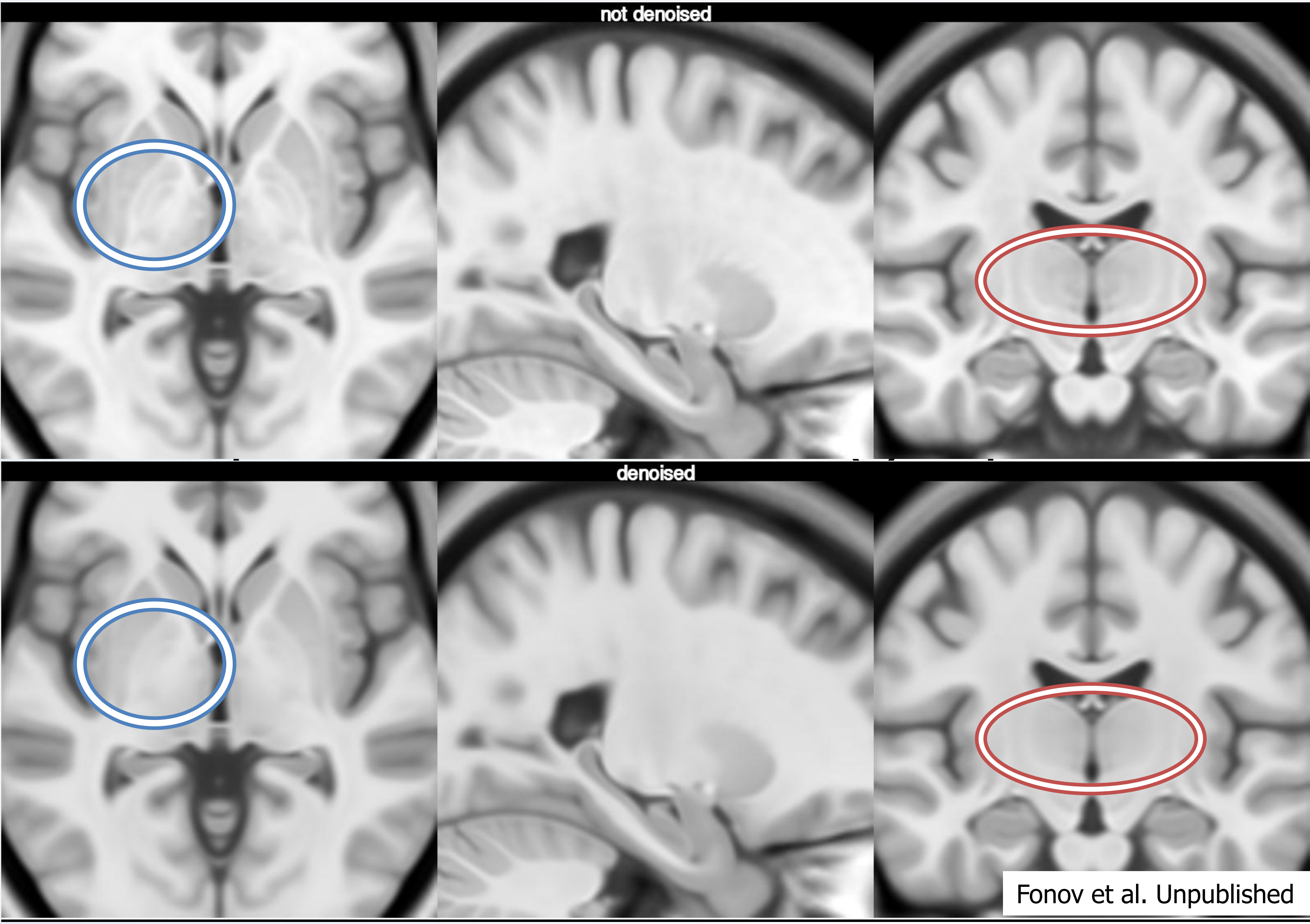




Coupé et al. 2008 IEEE TMI

Caution with Denoising

- Calibration is difficult
  - What is noise and what is edge?
  - Level of denoising should depend on the objectives



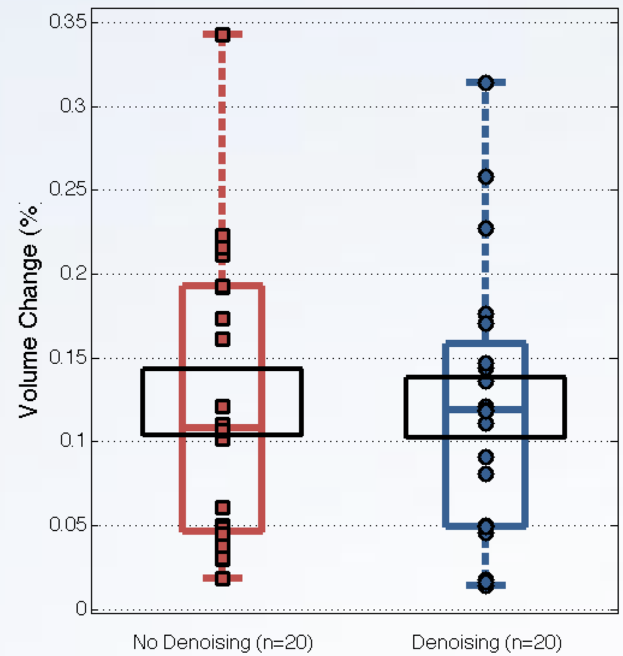
Fonov et al. Unpublished

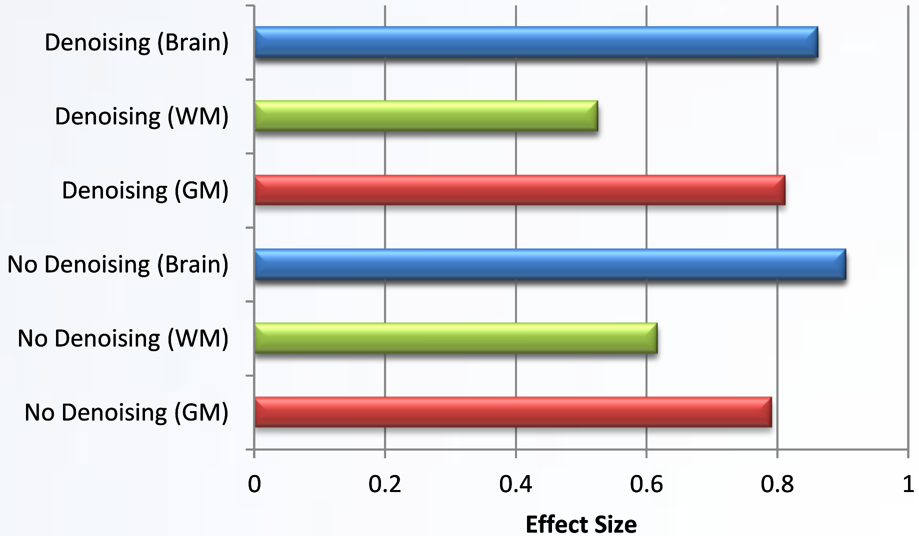
Effect of Noise Reduction

- On measurement of brain atrophy
  - Using Jacobian integration method
  - Analysis with and without denoising (nonlocal means)

- Reproducibility
  - Mean = 0.124% vs 0.120%

- Effect size
  - Larger = more powerful

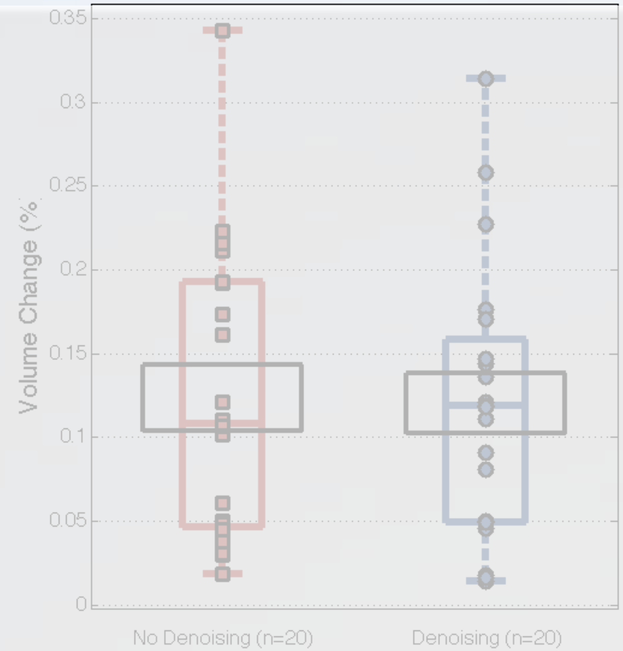


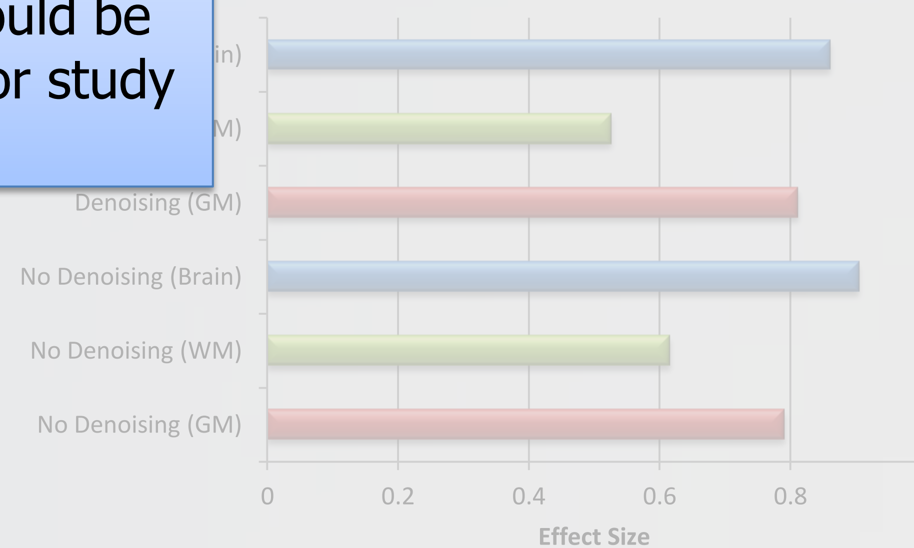


Nakamura et al Unpublished.

Effect of Noise Reduction

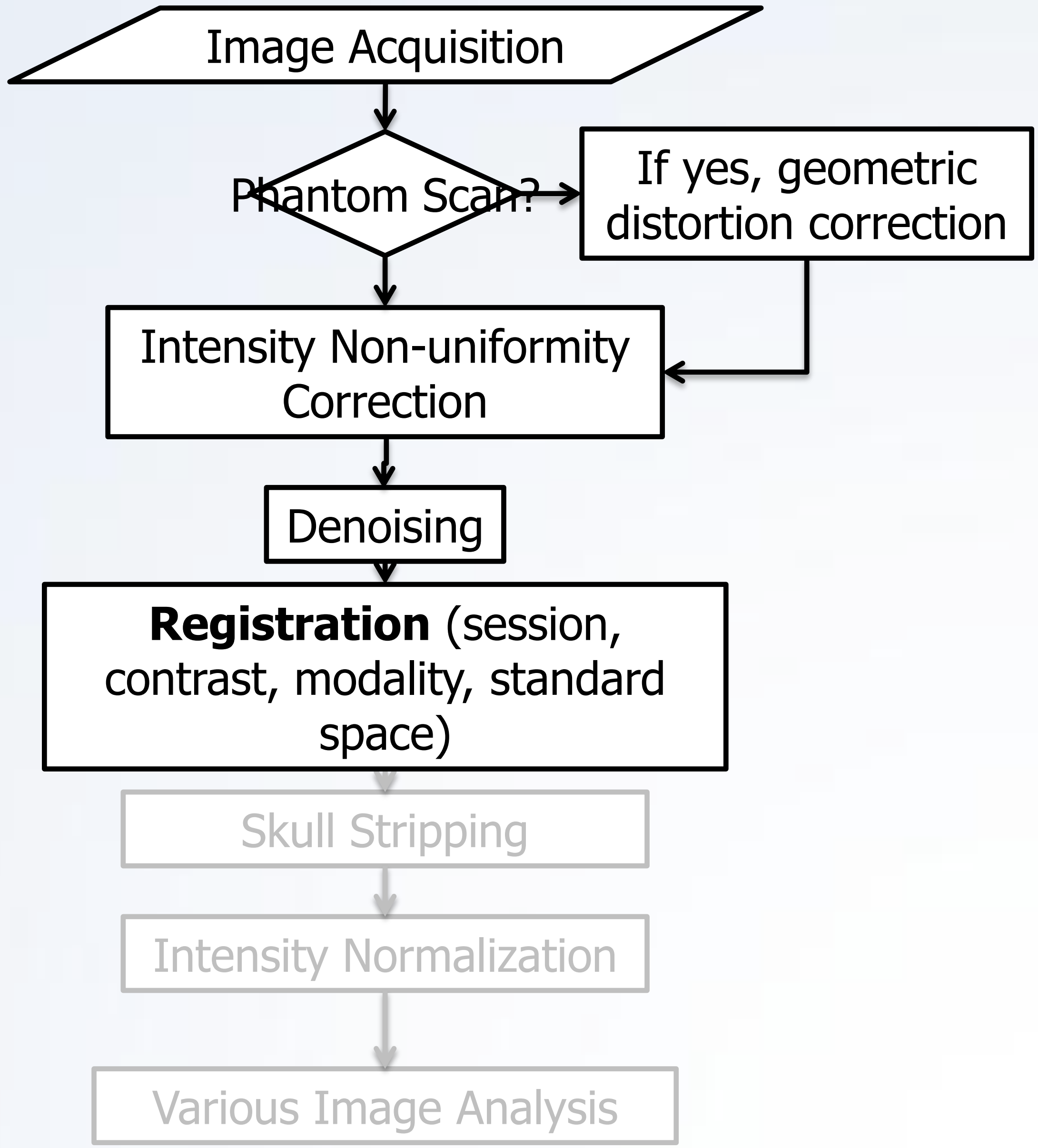
- On measurement of brain atrophy
  - Using Jacobian integration method
  - Analysis with and without denoising (nonlocal means)
- Scan-rescan reproducibility
  - Mean
- Effect si





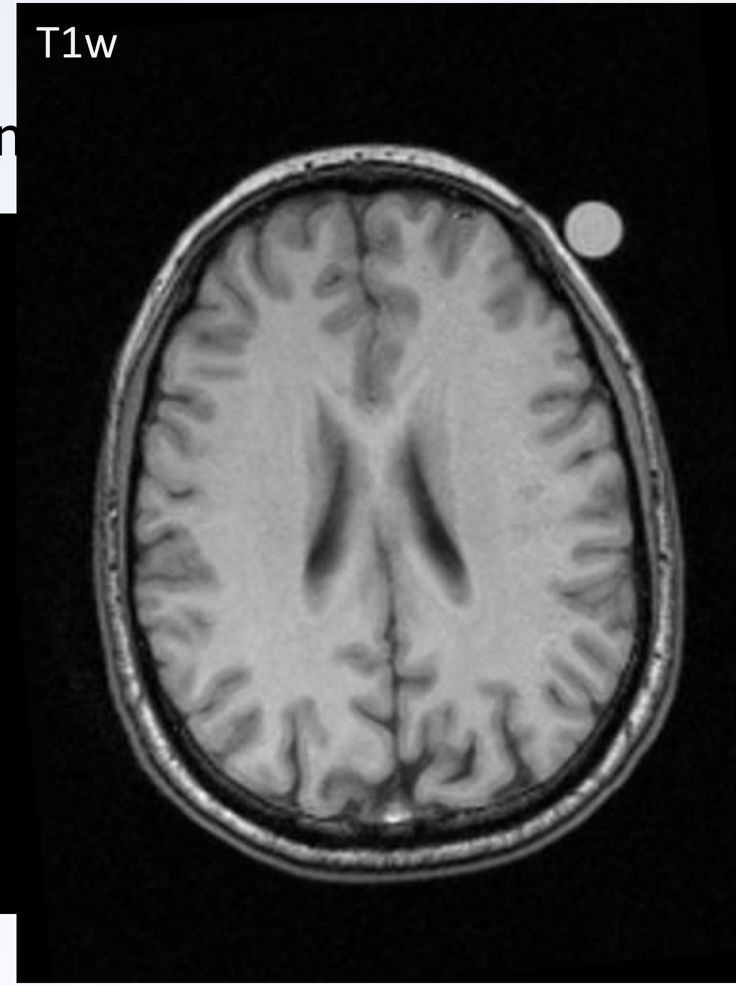
Summary:
- Denoising increases Contrast-to-Noise Ratio
- Level of denoising should be carefully considered for study objectives

Structural Image Preprocessing

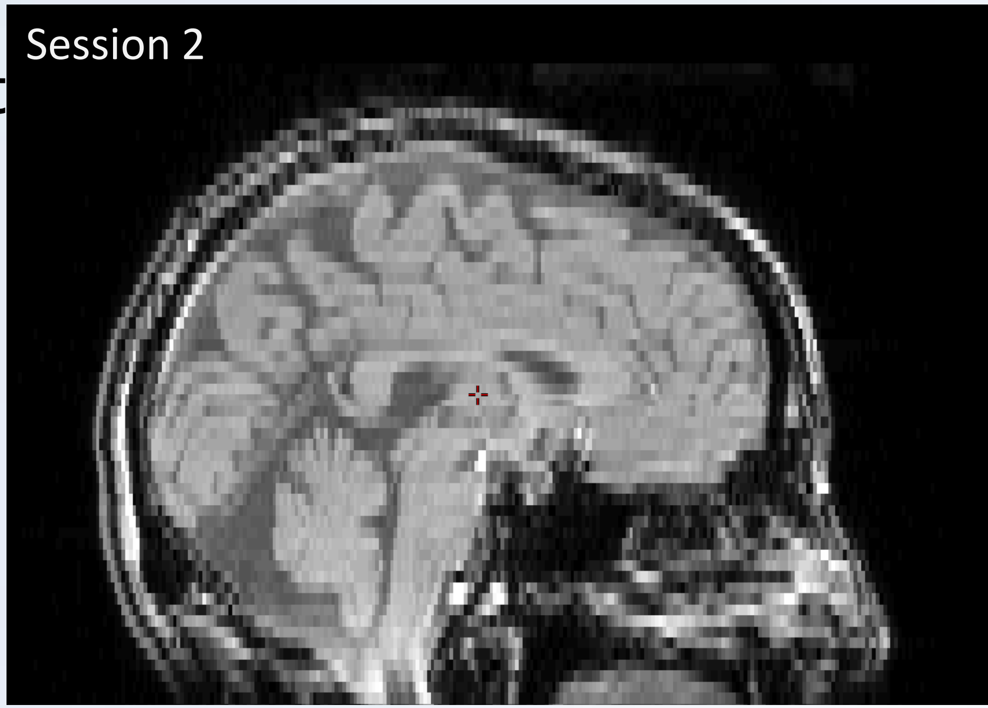


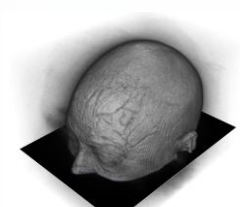
Motion Correction

- Inter-session
  - e.g. multiple sessions due to time constrain



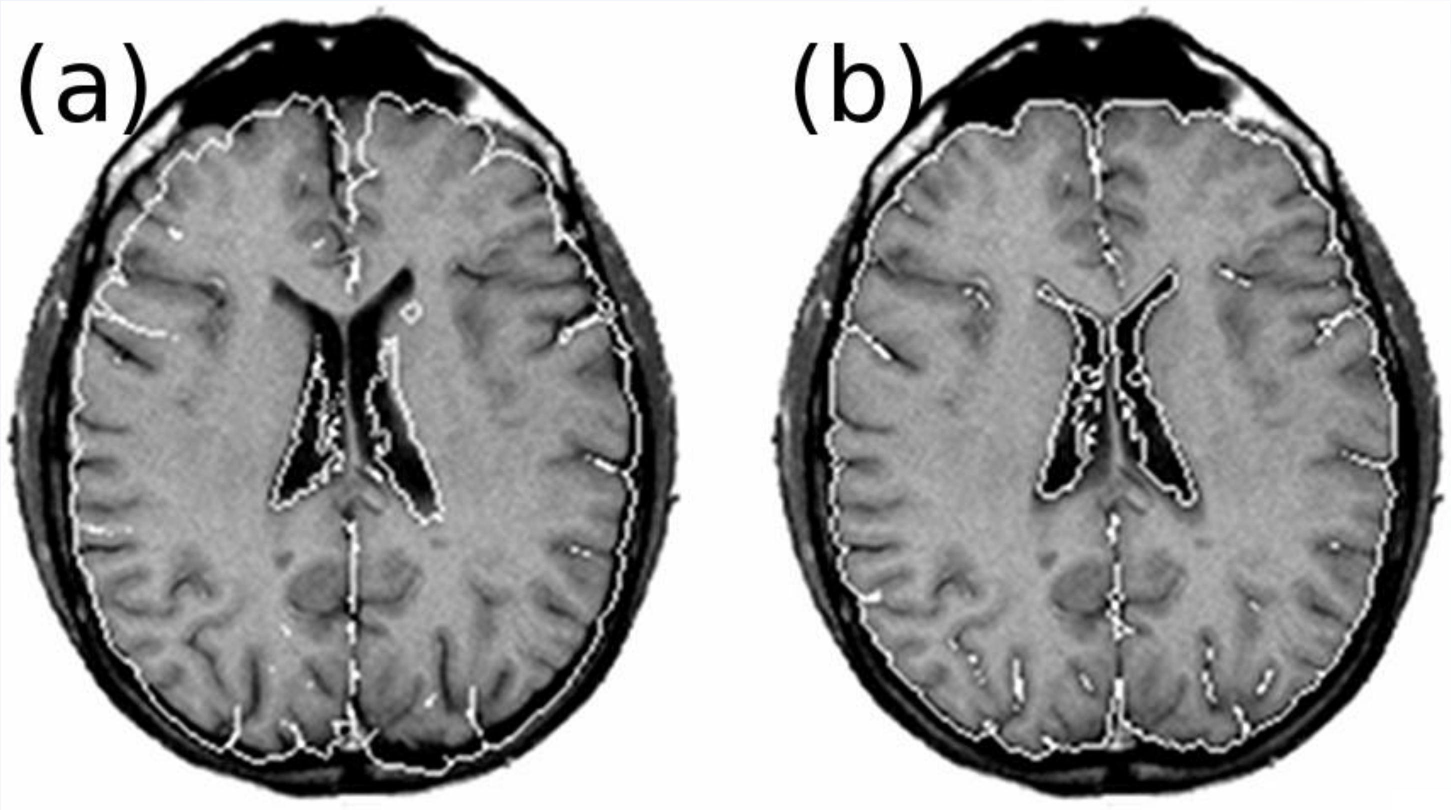
- Int



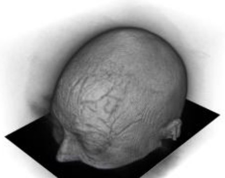


Motion Correction

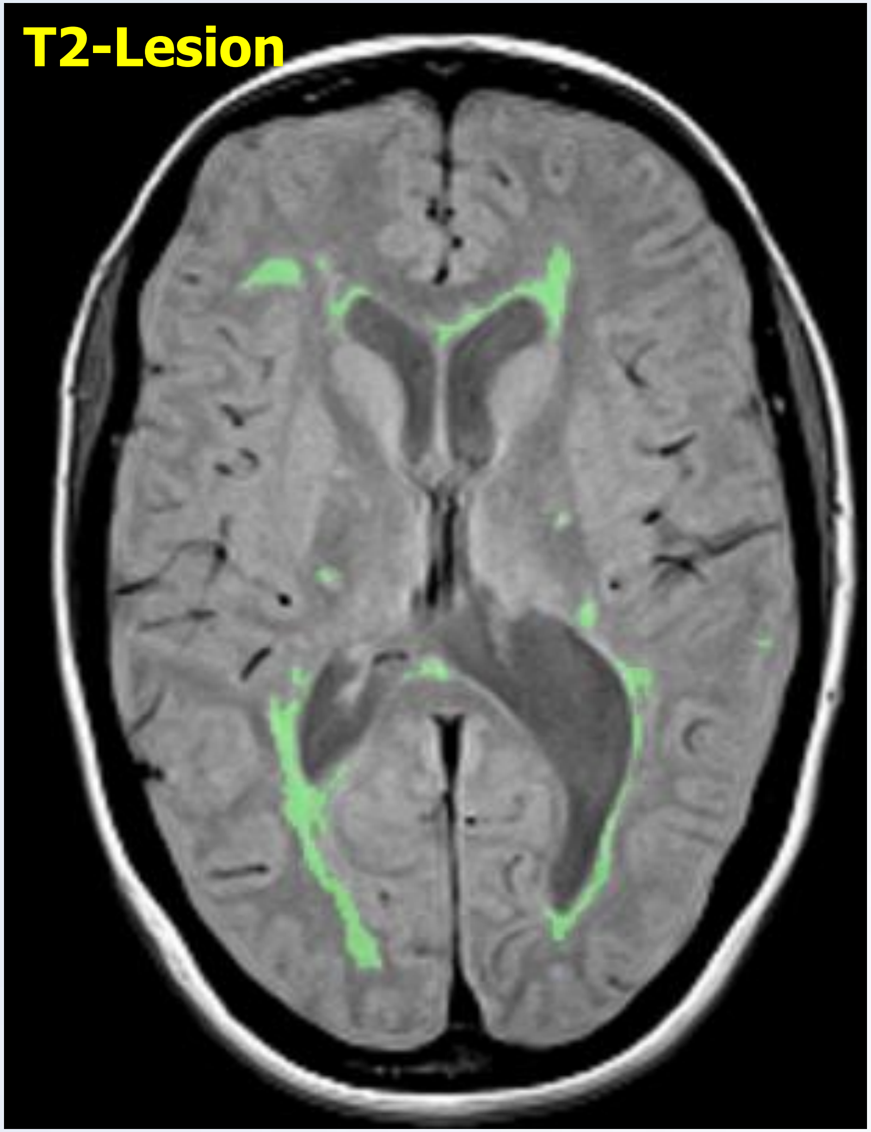
- Inter-session
- Intra-contrast

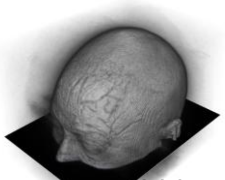


Nakamura PhD Thesis Case Western Reserve University 2011



Multispectral Bayesian Classifier to segment Multiple Sclerosis lesions

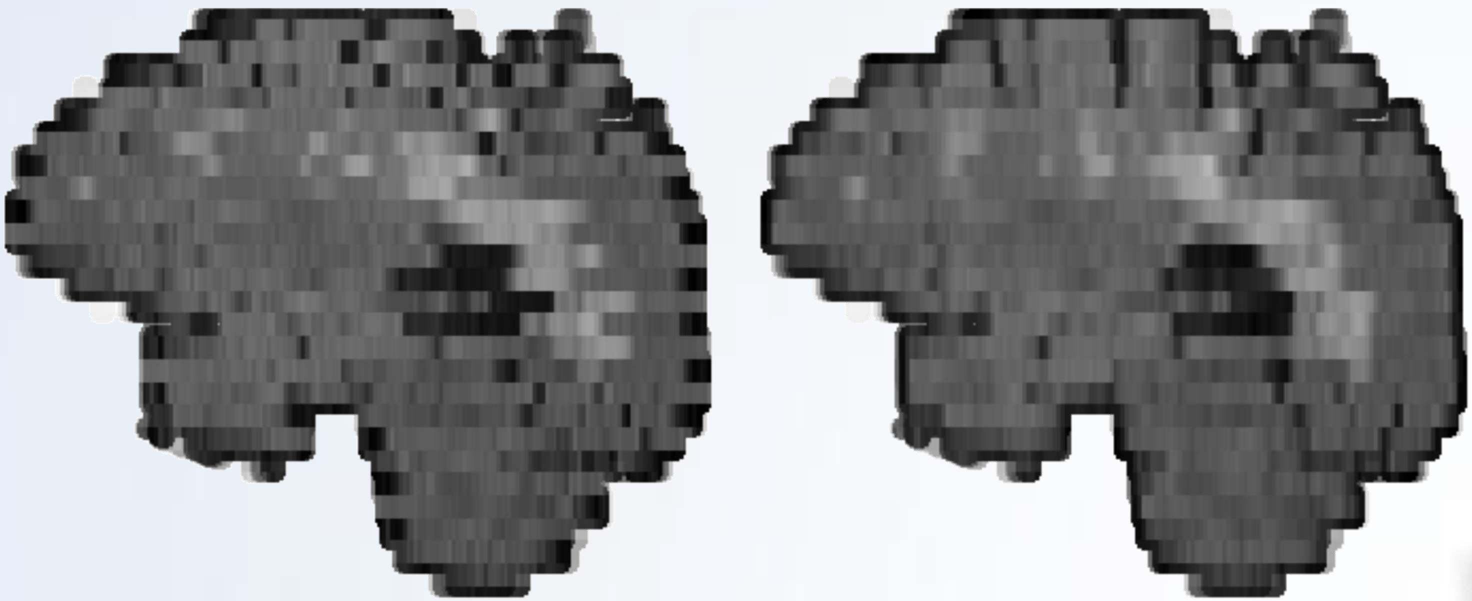




Francis MS Thesis McGill University 2004

Motion Correction

- Inter-session
- Intra-contrast
- Within image
  - Interleave (interpacket)

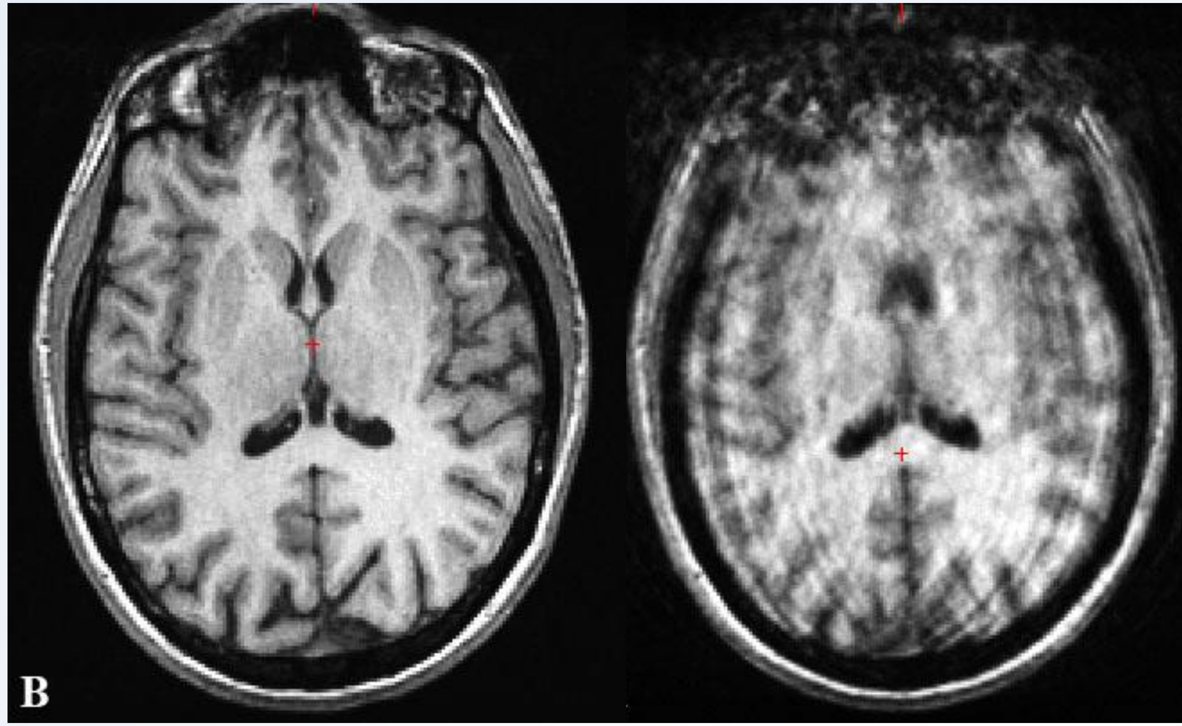


2-dimensional, multi-slice, axial FLAIR with 2 interleave acquisitions, shown sagittally

Nakamura PhD Thesis Case Western Reserve University2011

Motion Correction

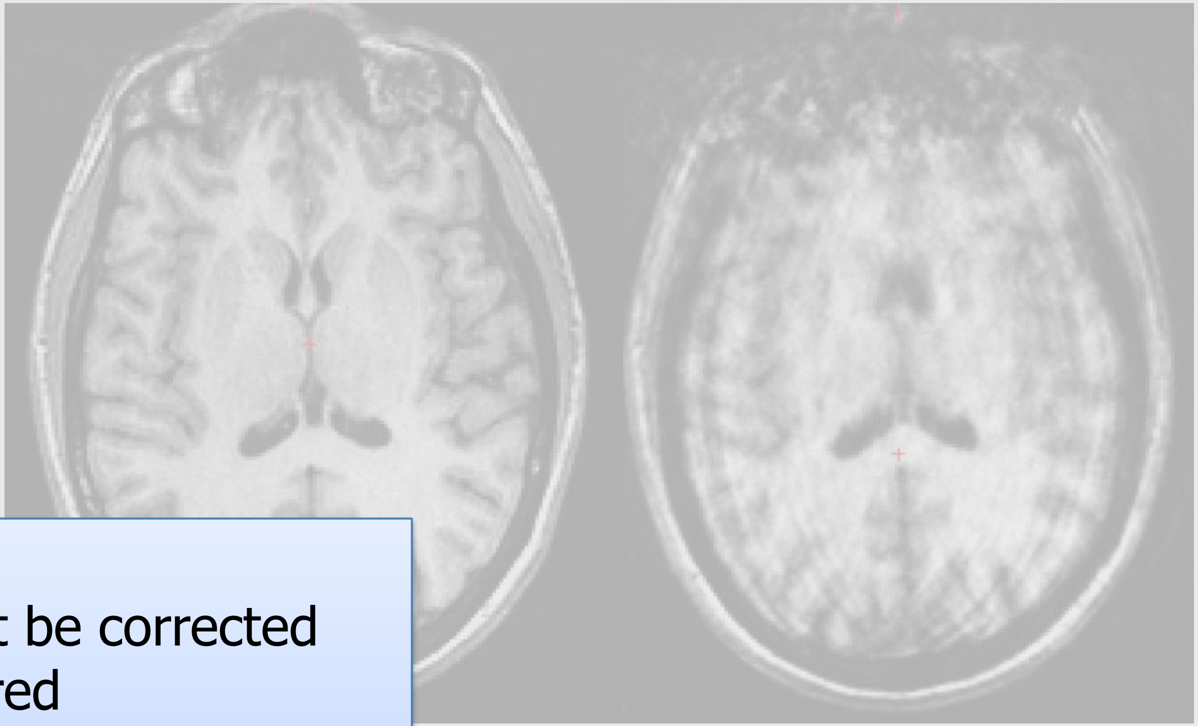
- Inter-session
- Intra-contrast
- Within image
  - Interleave (interpacket)
  - Ringing



http://www.mghradrounds.org/index.php?src=gendocs&link=2009_june

Motion Correction

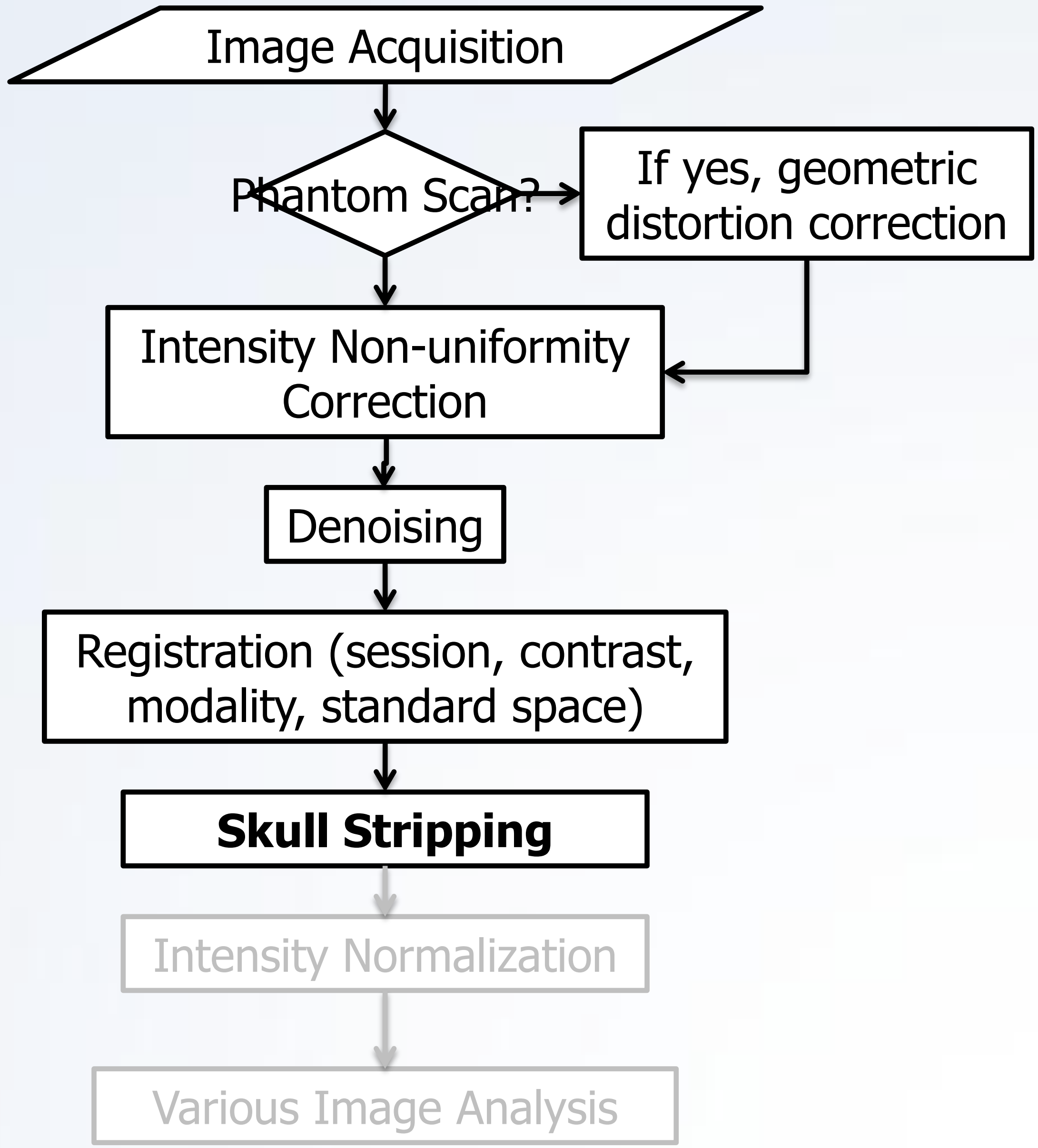
- Inter-session
- Intra-contrast
- Within image
  – Interleave (interpacket)
  – Ringing



Summary:
- Some motion cannot be corrected once image is acquired
- Critical to acquire ‘good’ images
  - Teaching/communicating with technicians, patients, & subjects
- Some types of motion can be corrected during pre-processing
  - But it may lead to other artifacts

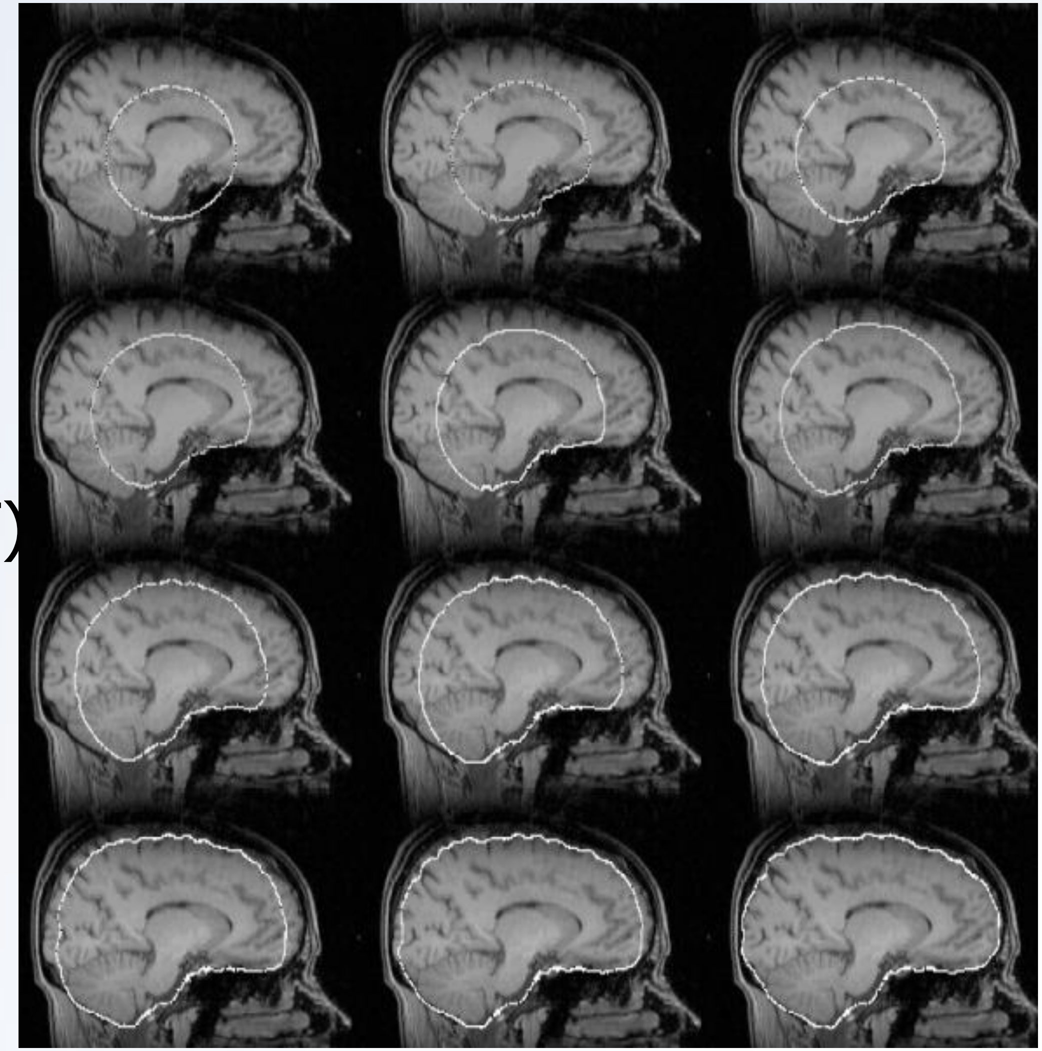
http://www.mghradrounds.org/index.php?src=gendocs&link=2009_june

Structural Image Preprocessing



Skull Stripping

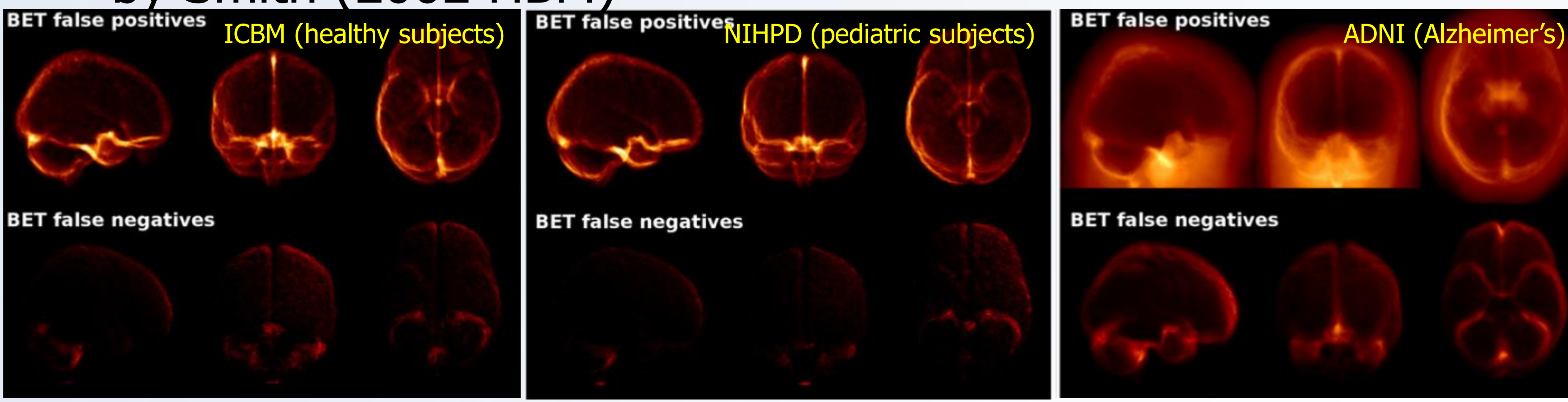
- a.k.a. brain extraction
  - Brain parenchyma
  - Brain parenchyma plus cerebrospinal fluid
- FSL
  - Brain extraction tool (BET) by Smith (2002 HBM)



Smith 2002 HBM

Skull Stripping

- a.k.a. brain extraction
- FSL
  - Brain extraction tool (BET) by Smith (2002 HBM)



False Positive = Non-brain falsely marked as brain
False Negative = Brain falsely marked as non-brain

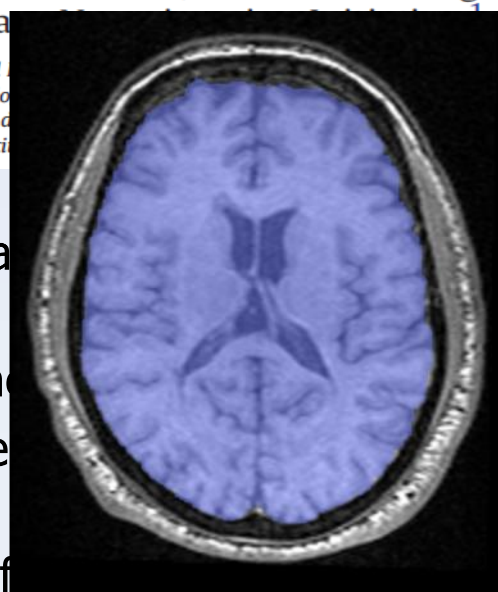
Eskildsen et al 2012 NeuroImage

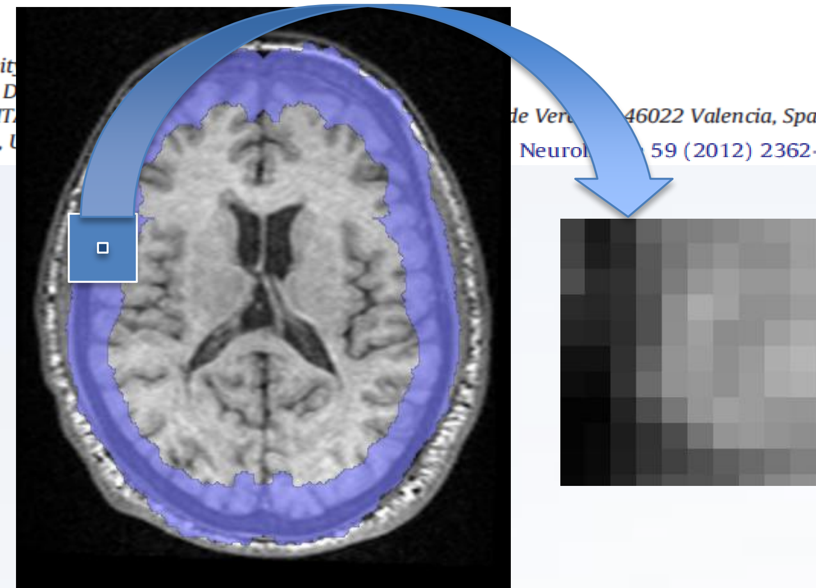
BEaST: Brain extraction based on nonlocal segmentation technique

Simon F. Eskildsen [a,b,*], Pierrick Coupé [a], Vladimir Fonov [a], José V. Manjón [c], Kelvin K. Leung [d], Nicolas Guizard [a], Shafik N. Wassef [a], Lasse Riis Østergaard [b], D. Louis Collins [a]
and The Alzheimer's Disea

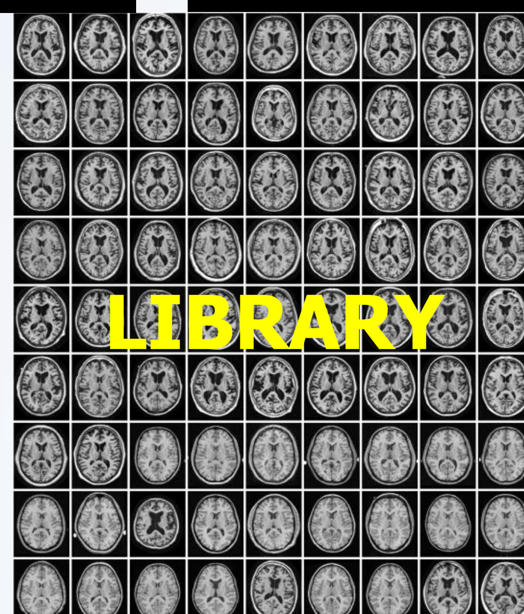
[a] McConnell Brain Imaging Centre, Montreal ... ersit
[b] Department of Health Science and Technolo ... org, D
[c] Instituto de Aplicaciones de las Tecnologías ... as (IT ... de Ver ... 46022 Valencia, Spain
[d] Dementia Research Centre (DRC), UCL Insti ... BBG, U

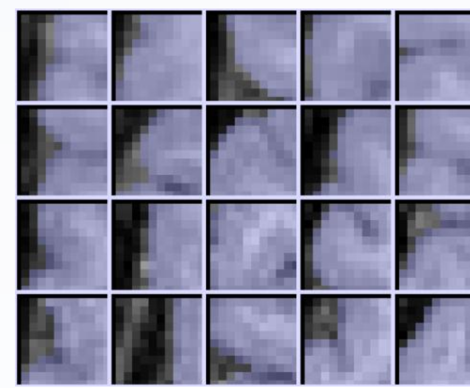
Neurol ... 59 (2012) 2362–2373





- Find the marginal a
  and non-brain
- For each pixel in th
  - Find the local ne
  - Find the images
    intensity profile f
  - Use brain labels from library
  - Determine if this voxel is brain or non-brain

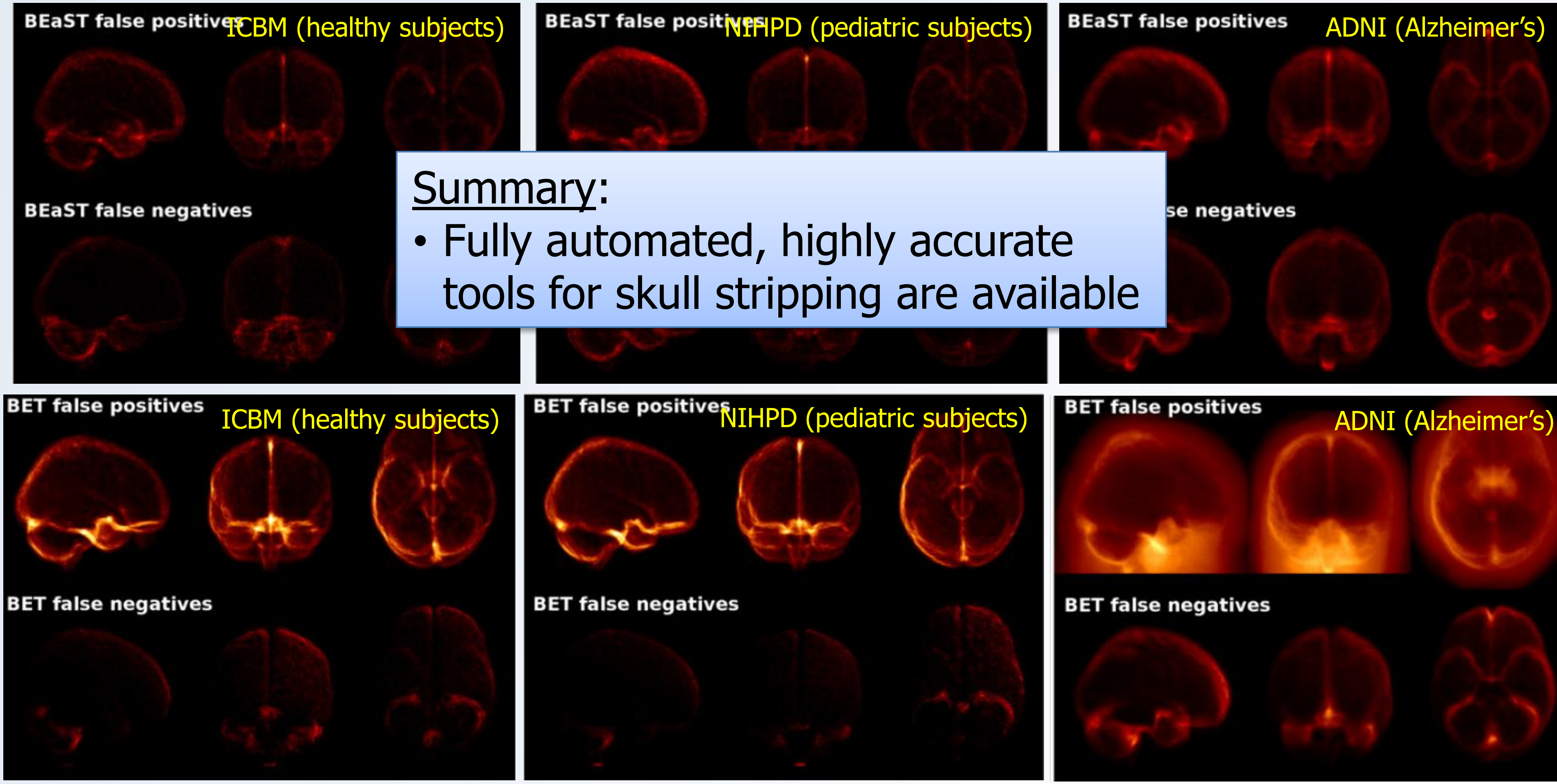




Eskildsen 2012 NeuroImage

Skull Stripping

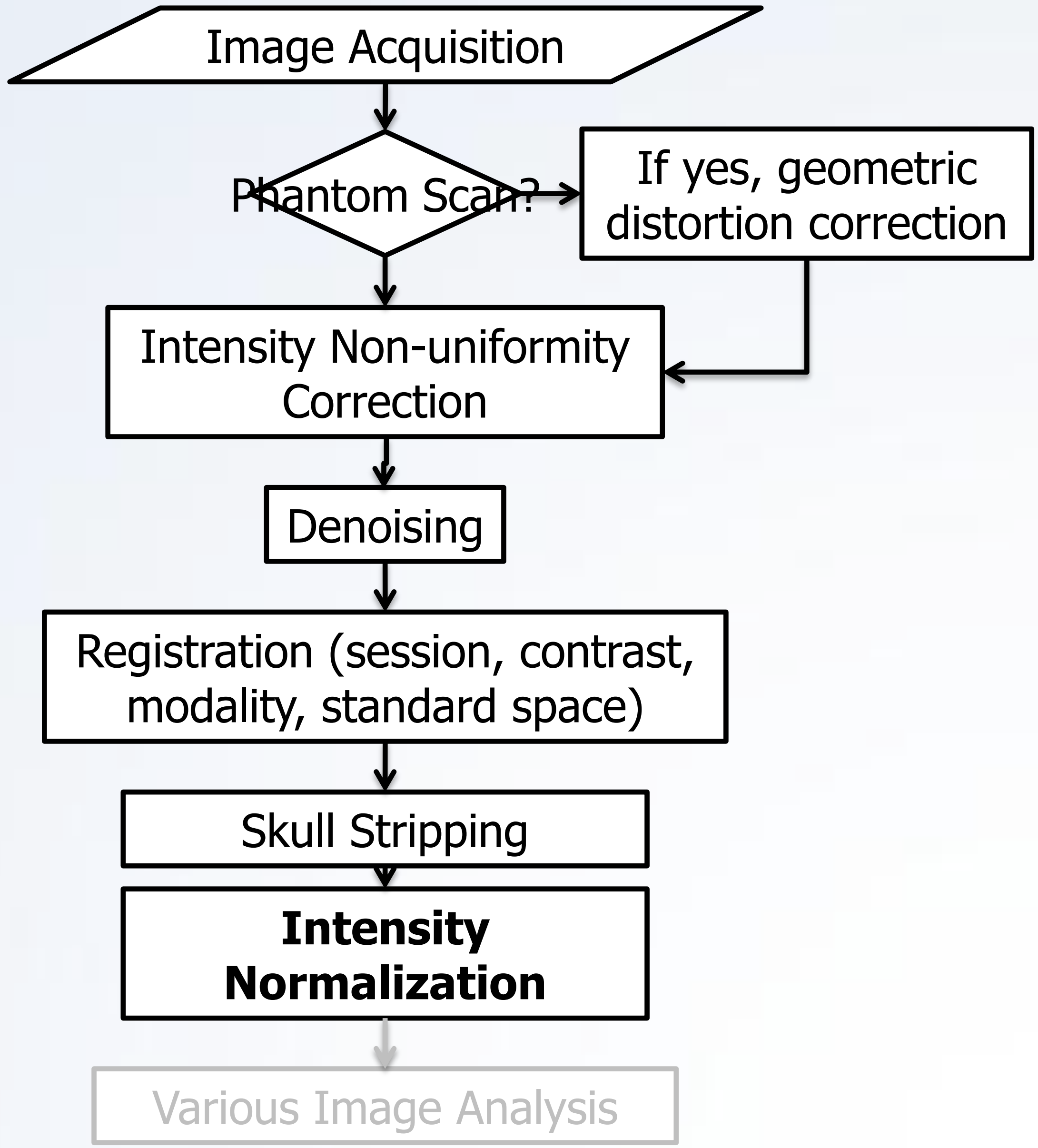
- Brain Extraction based on nonlocal Segmentation Technique



<u>Summary</u>:
- Fully automated, highly accurate tools for skull stripping are available

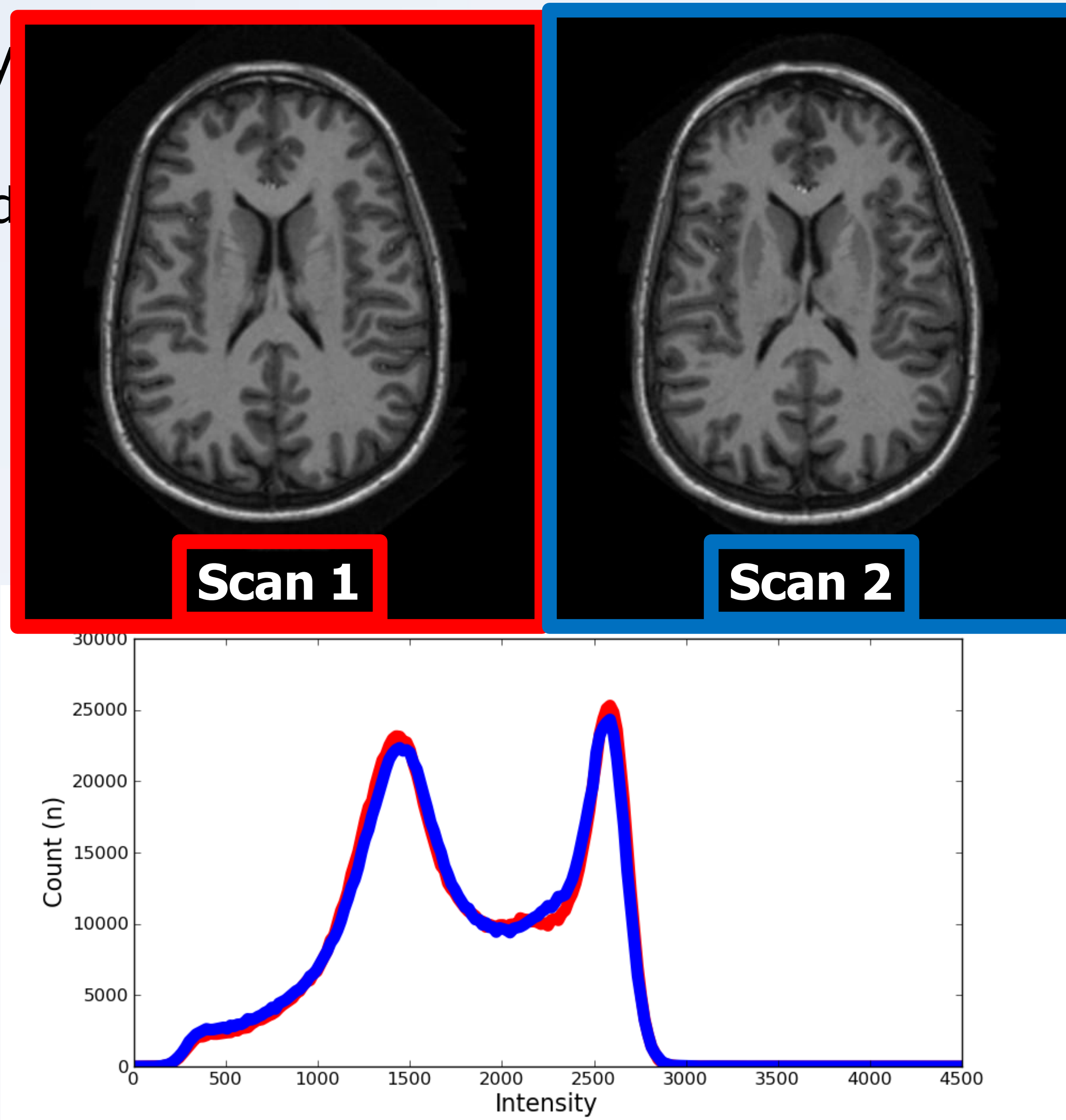
Eskildsen 2012 NeuroImage

Structural Image Preprocessing

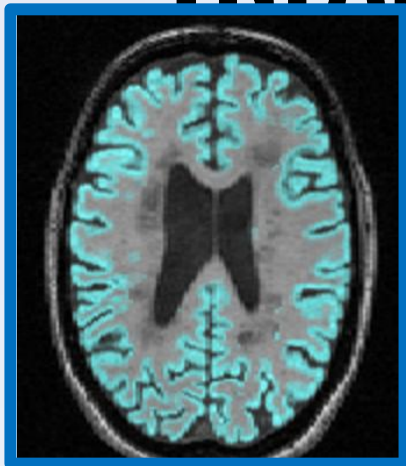


Intensity Normalization

- To standardize intensity range
  - May be necessary depending on image processing and study protocol

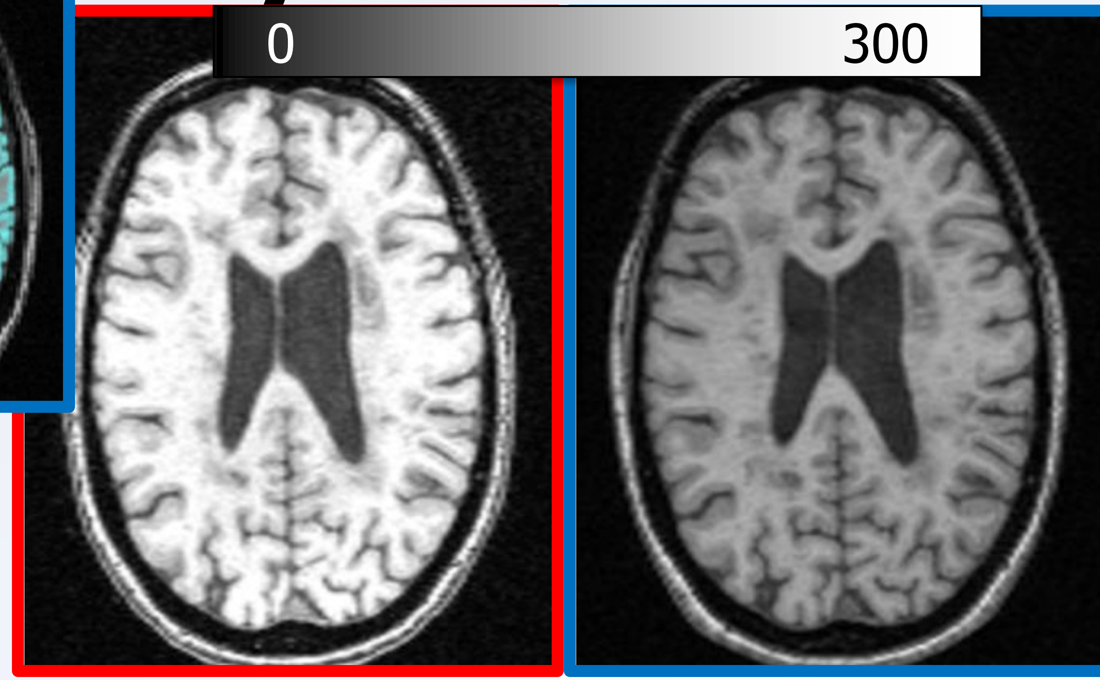


Intensity Normalization

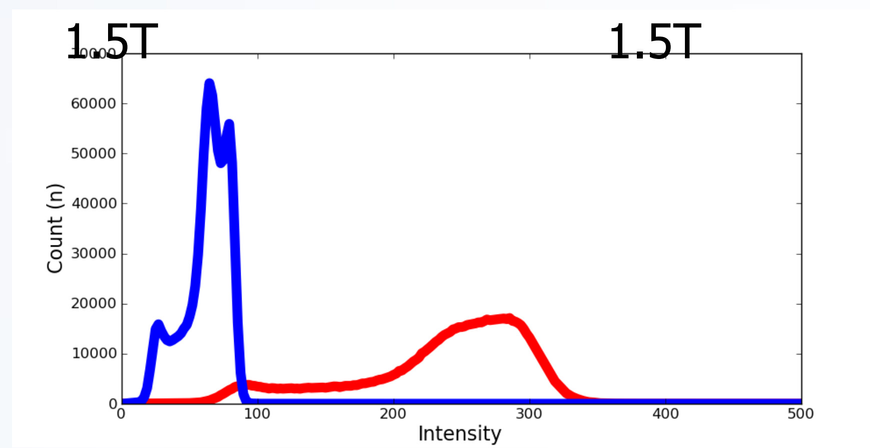


614cc 623cc

+1.4% difference

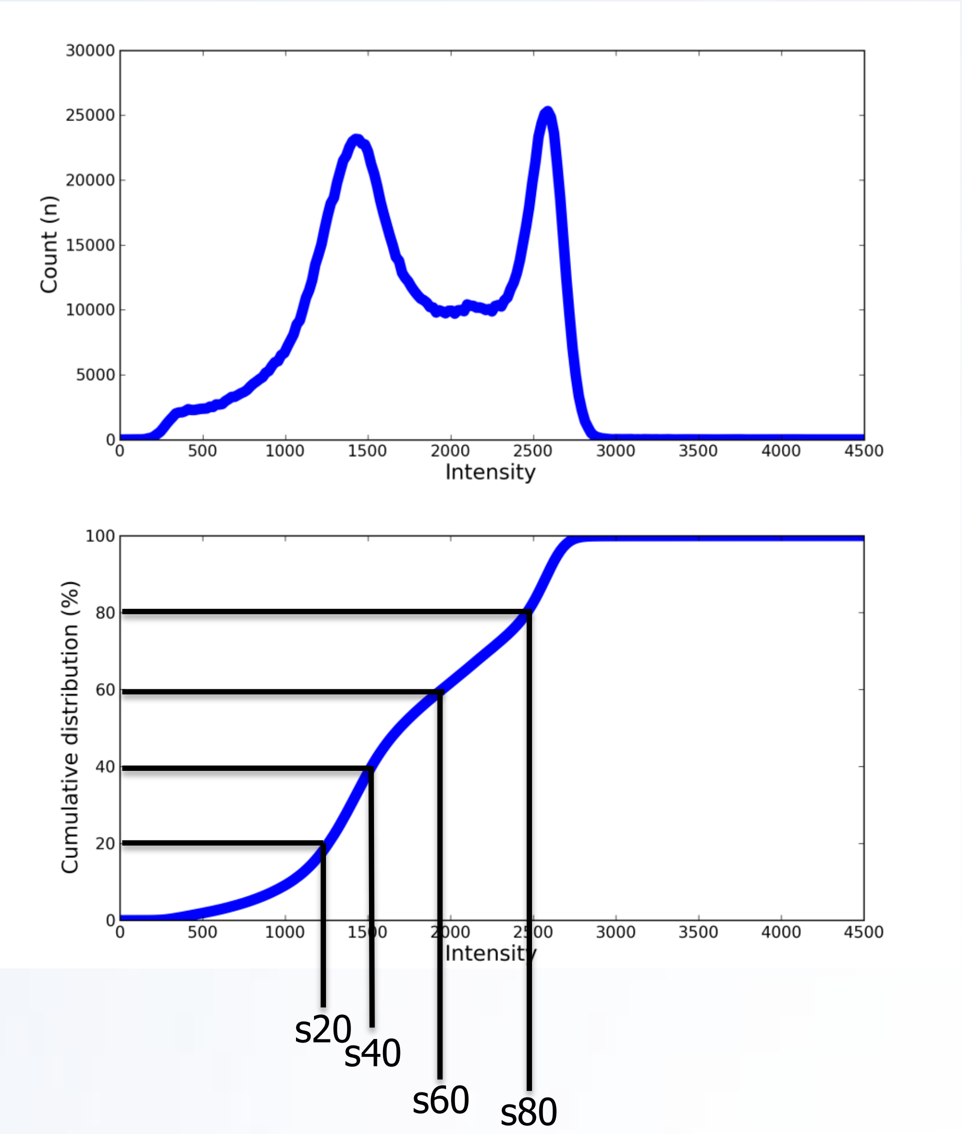


	GE Medical	Philips Medical
Manufacturer =	GE Medical	Philips Medical
Model =	Signa Excite	Infinion
Magnetic Field =	1.5T	1.5T



Intensity Normalization Example

- Nyul's method
  - Conventional and typical intensity standardization metho
  - Piecewise linear approach

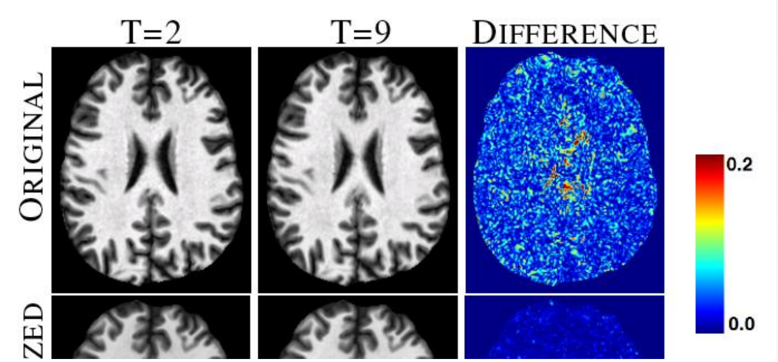


- Create histogram
- Create cumulative histogram
- At each interval (20% here)
  - Find the intensity on image
  - Transform intensity to standard scale (s20,s40…)

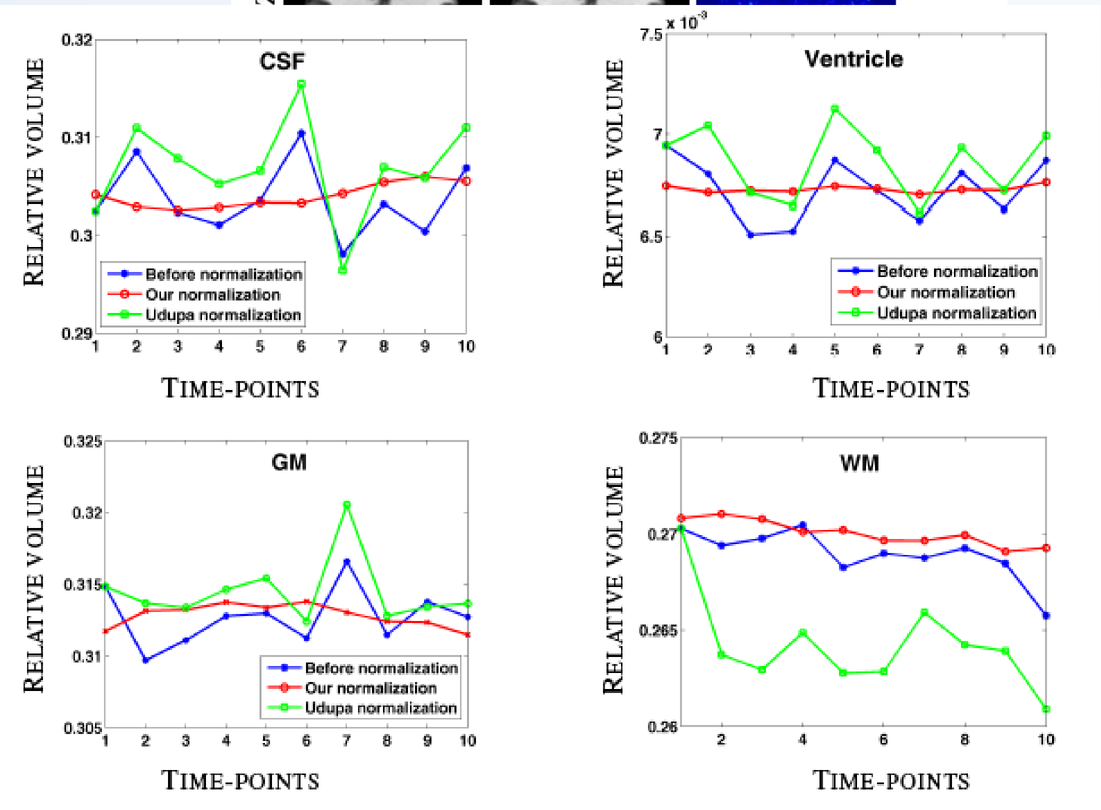
Nyul and Udupa 1999 MRM

Impact of Intensity Normalization

- Longitudinal volumetric study
- Apply intensity normalization
  - Auto-regression model
  - Takes advantage of time-series data



- Tissue volumes from wee
  MRIs
- BLUE
  - Un-normalized MRIs
- RED
  - Normalized images
- GREEN:
  - Traditional normalization (Nyul)



Roy 2013 IEEE ISBI

Impact of Intensity Normalization

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- Apply intensity normalization
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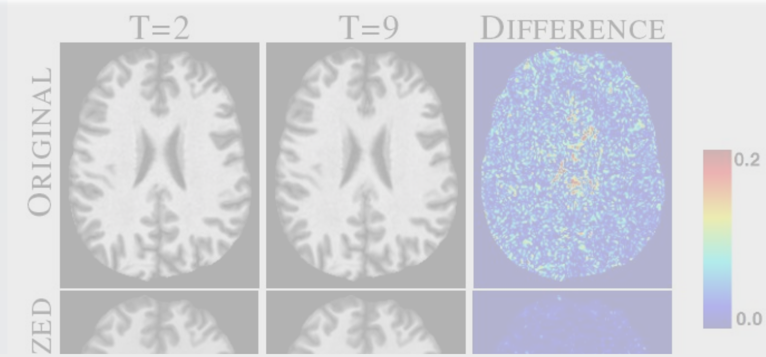


- Traditional normalization (Nyul)

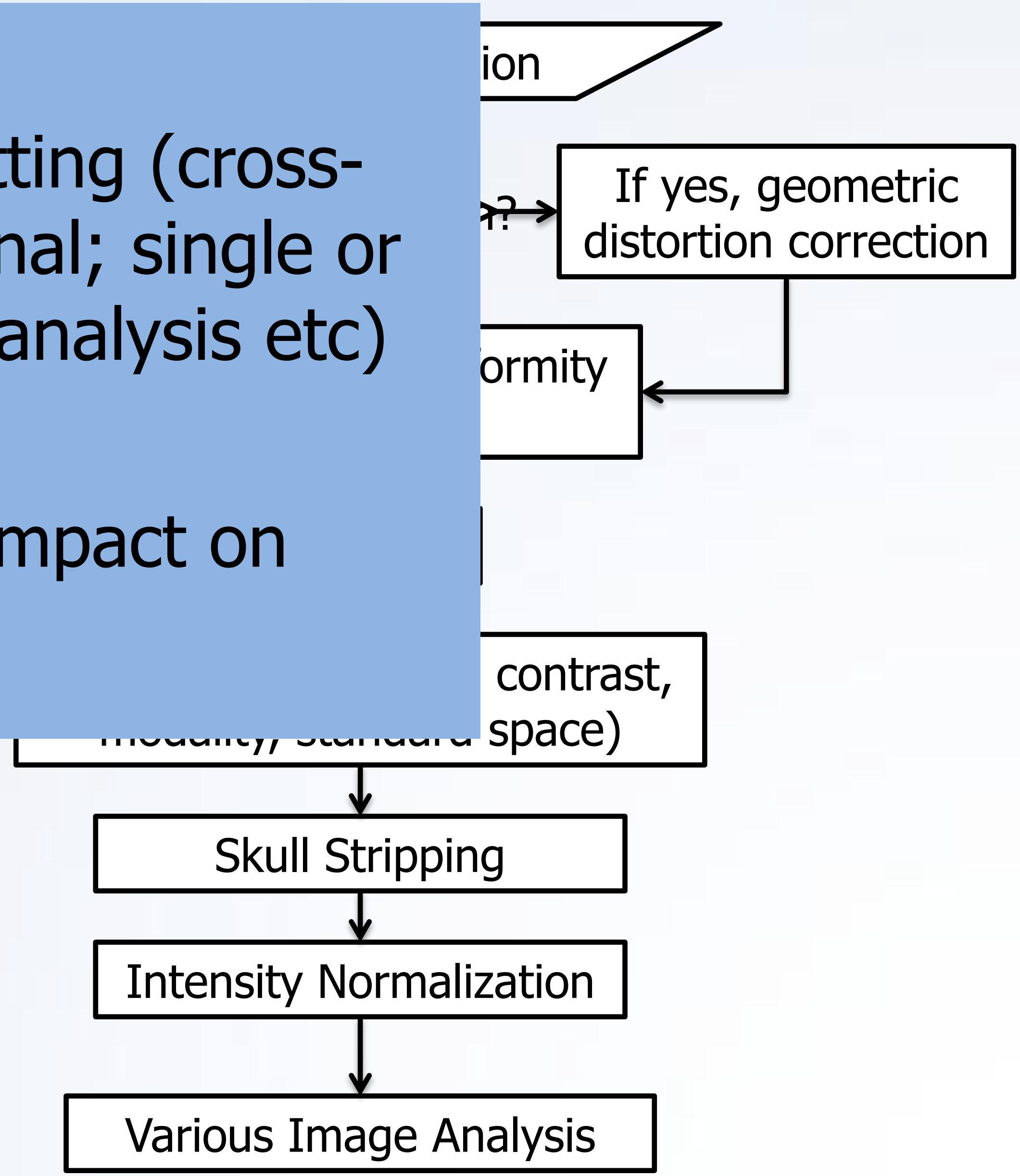
<u>Summary</u>:
- Necessity of intensity normalization depends on application
- Advanced methods are recommended
  - Overly simplistic methods may worsen your results

Roy 2013 IEEE ISBI

Example of Pre-processing Steps

Pre-processing

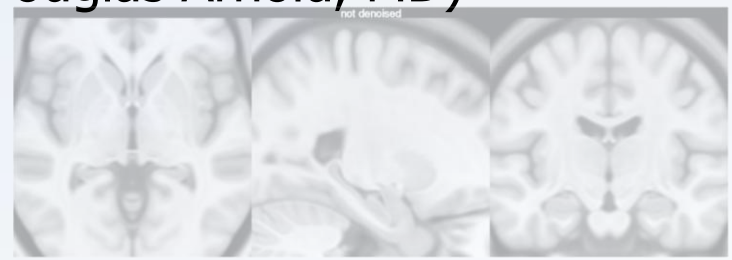
- depends on study setting (cross-sectional vs longitudinal; single or multi- center; image analysis etc)
- is often overlooked
- can have significant impact on study outcome

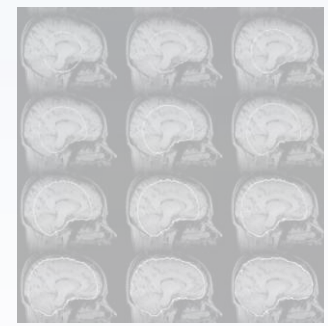


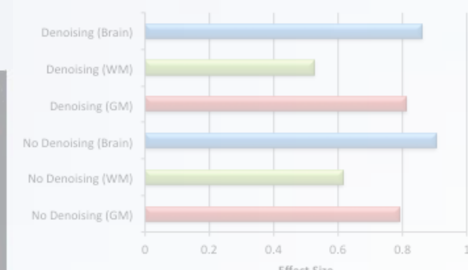
Acknowledgement

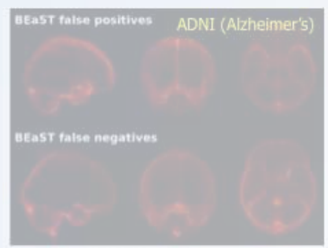
- Magnetic Resonance Spectroscopy Unit (PI: Douglas Arnold, MD)
  - Sridar Narayanan, PhD
  - Haz-Edine Assemlal, PhD

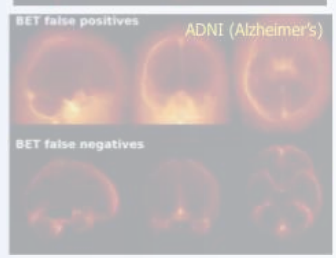
- Image Processing Laboratory (PI: Louis Collins, PhD)
  - Vladimir Fonov, PhD
  - Nicolas Guizard, MEng

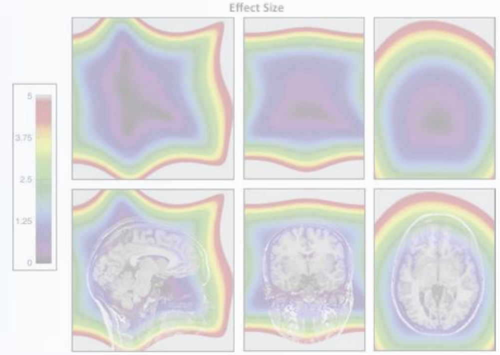


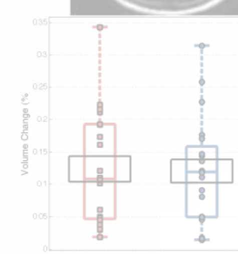


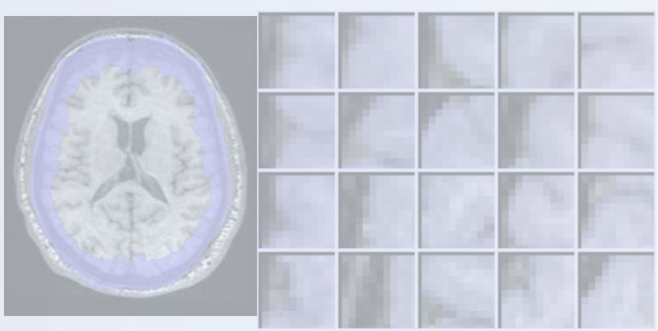












kunio.nakamura@mcgill.ca