

Run-time correction of MRI inhomogeneities to enhance warping accuracy

Evan Fletcher



Approaches to bias correction

1. Non-template based

Adjust images to improve some quality measure
(e.g. N3, bfc)

Done in the absence of known true values

2. Template based

Do comparisons between like tissue types of
different images (Fox & Lewis, Colin *et al.*)

With known lack of bias in template, this results in
more certain correction

Problems of bias correction

➤ Model 1

Cannot be sure of “ground truth:”

Must adjust image closer to hypothetical qualities


➤ Model 2

Demands known similarity of tissue types

Benefits to run-time correction

- Improve images more accurately than with non-template based correction models
- Improve fidelity and stability of Jacobians derived from warps

Method of run-time correction

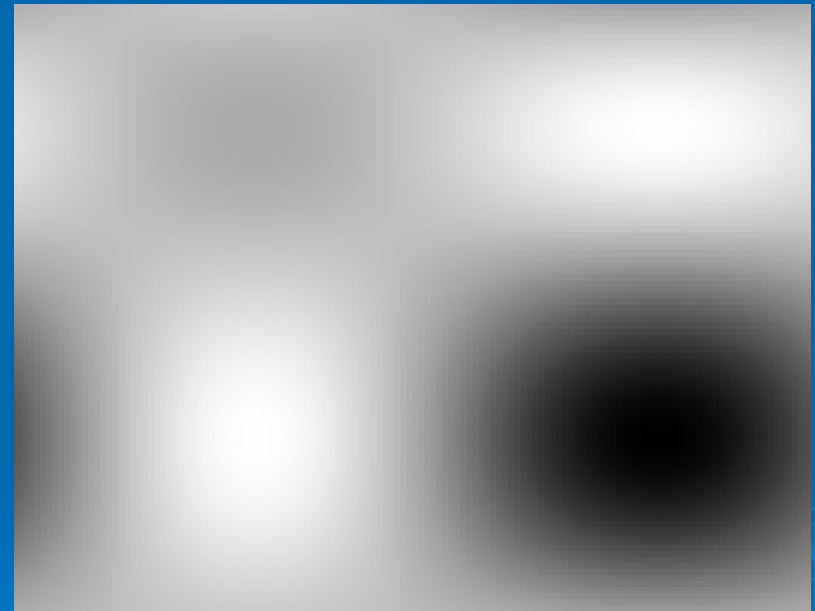
1. Directly compare tissue intensities of 2 images at first stages of warping hierarchy
 2. Rely on smoothing and warp hierarchy to successively approximate matching of like tissues
 3. Estimate bias correction field as inverse ratio of intensities
 4. Apply latest correction field before each warp iteration
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Bias Fields

- Bias field model

$$Y = B * X + E$$

- X is true voxel value
- Y is measured voxel value
- B is local varying multiplicative bias
- E is Gaussian noise

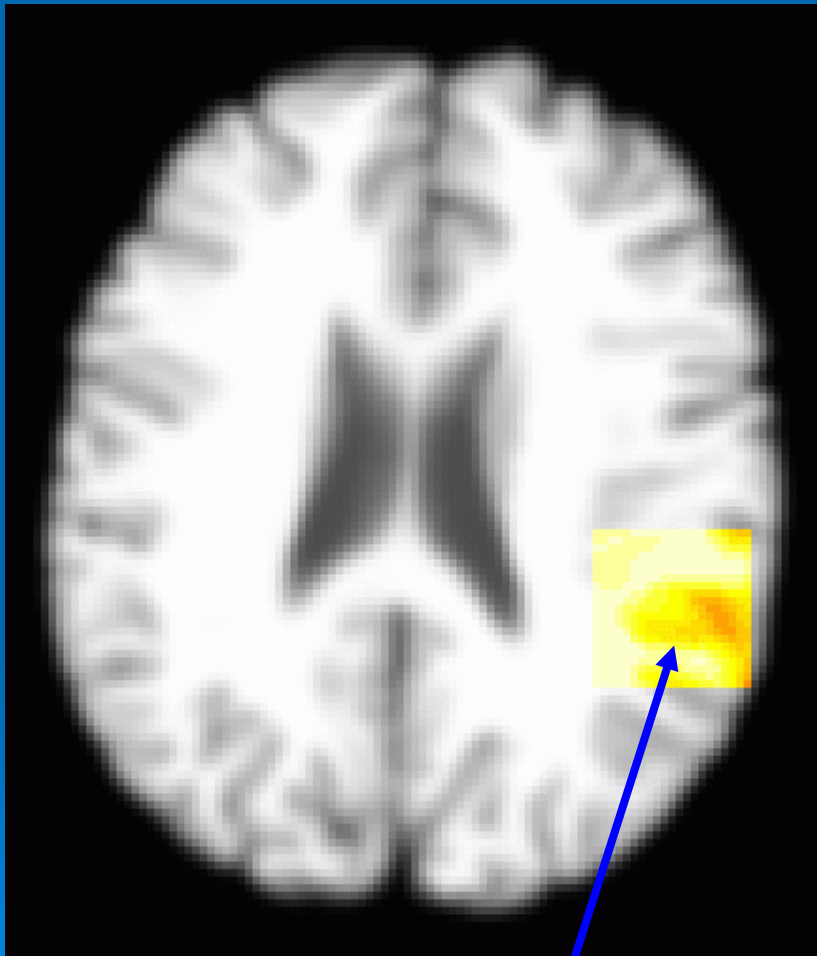


Slice of sinusoidal bias field

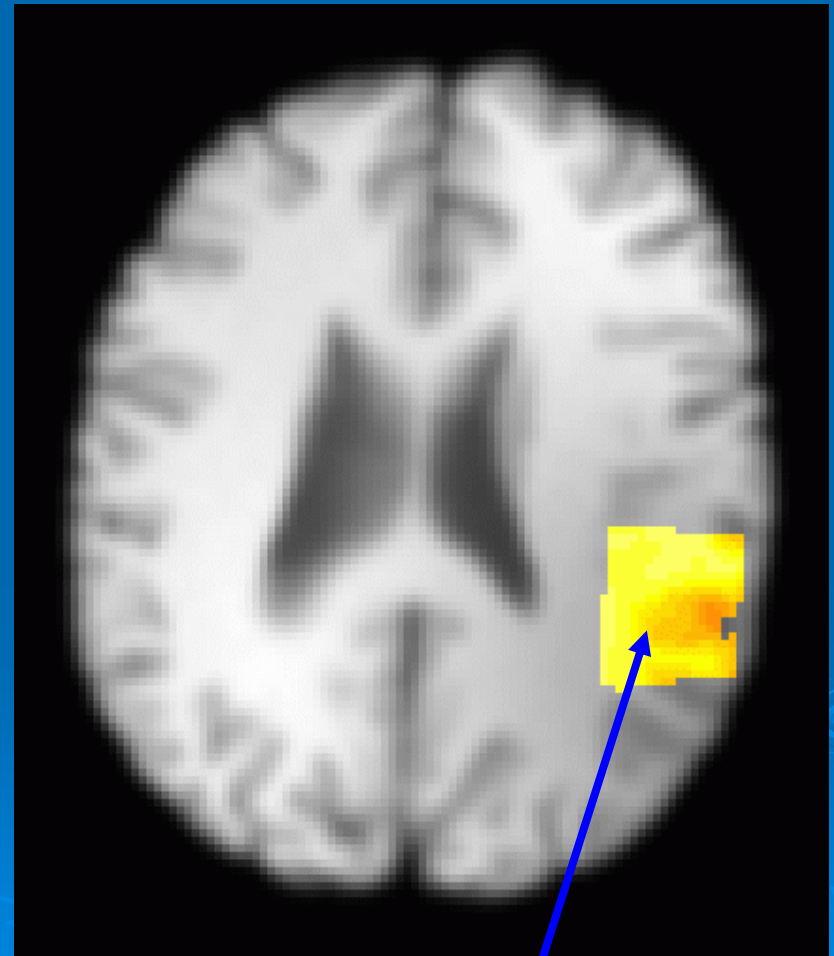
Correction step 1

template

subject



Sampling cube in template

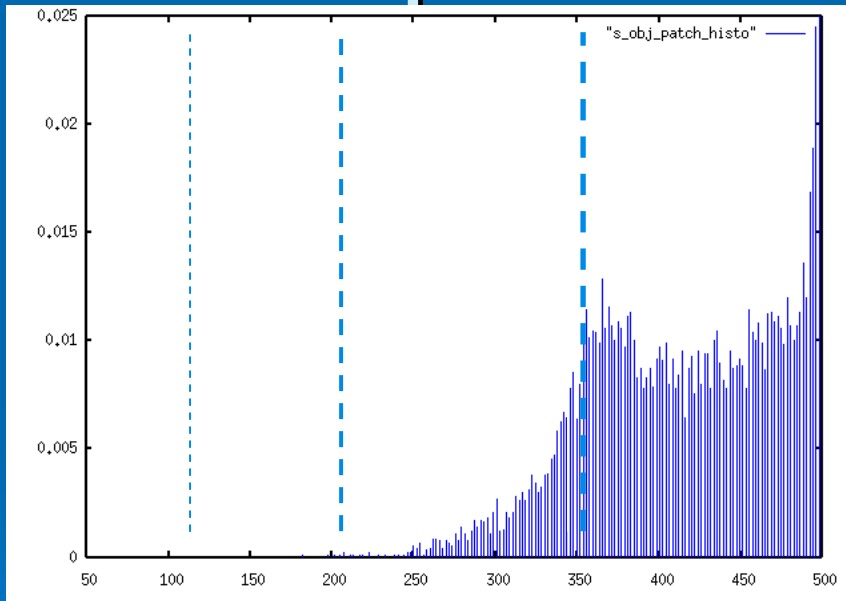


Warped image of sampling cube

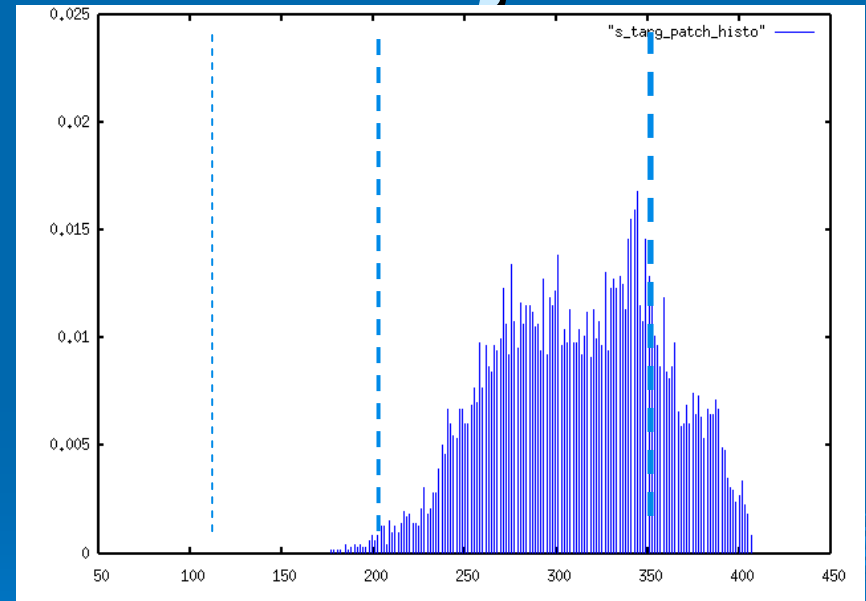
Histograms of patches

Divide into sub ranges

template



subject



Sampling local bias ratio

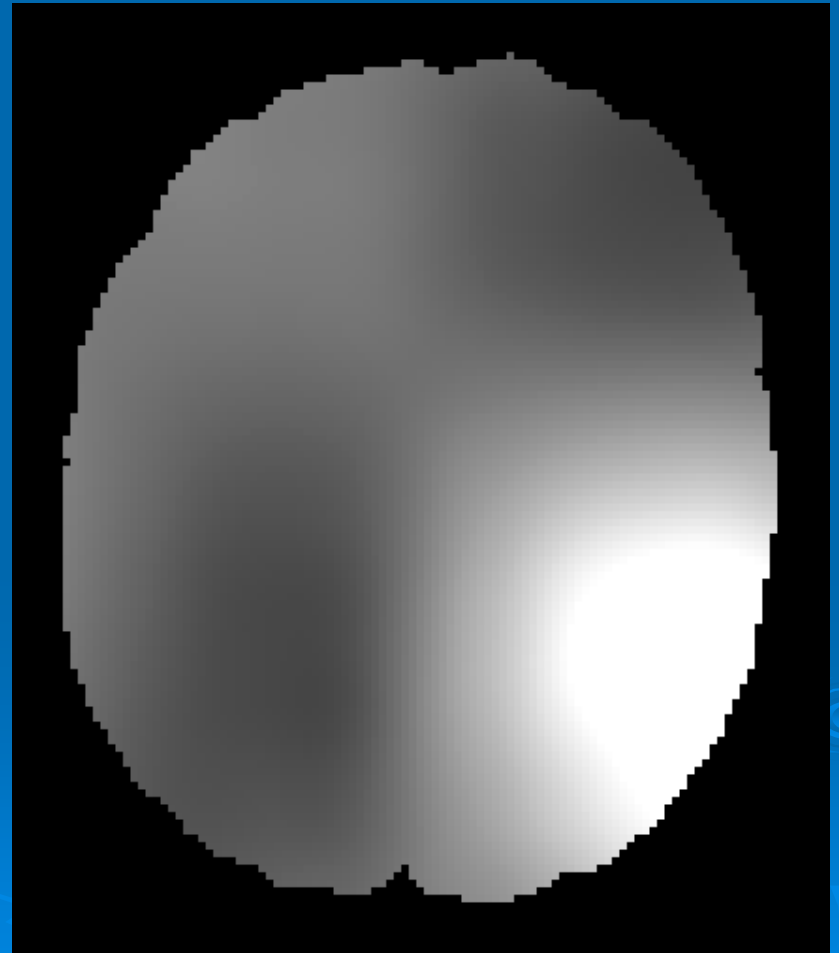
- Voxels in template warped into subject
- Find common sub range with most shared voxels

This example

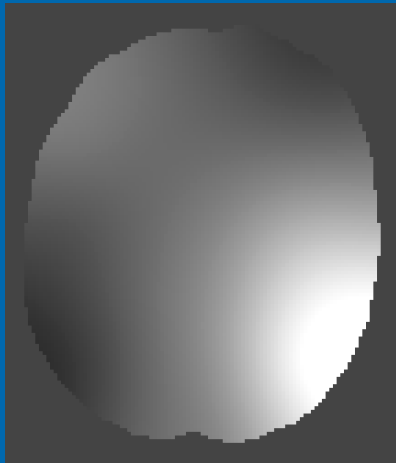
- Highest sub range has most shared voxels (1661)
- Ratio of means for this range is 1.32
- Local bias correction estimate is $1/1.32 = 0.76$

Creating smooth bias correction fields

1. Sample bias ratios at grid points
2. Use TP-Spline interpolation for smooth correction field
3. Apply multiplicatively to subject image before next warp iteration
4. Unbiased template
→ **absolute** bias correction

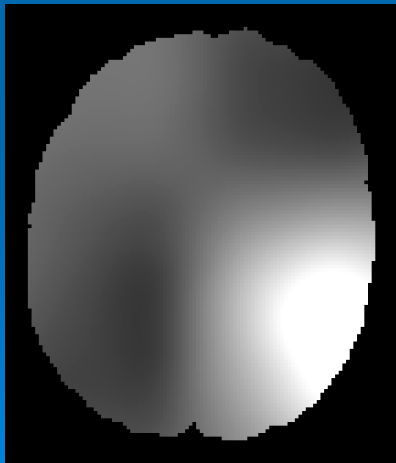
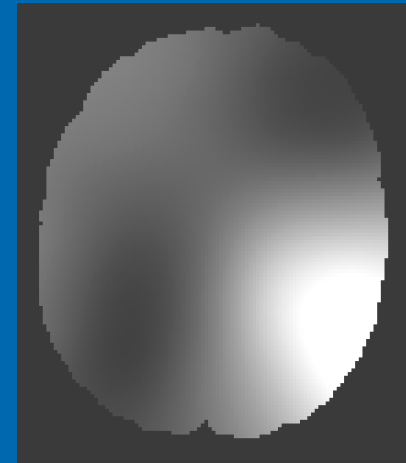


Evolution of bias correction field: Successive refinement & sampling of bias ratios



24 mm

12 mm



7.2 mm

6mm

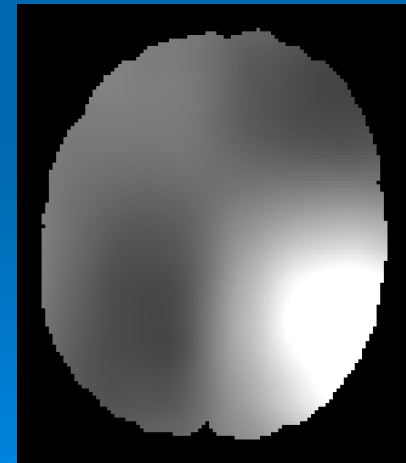
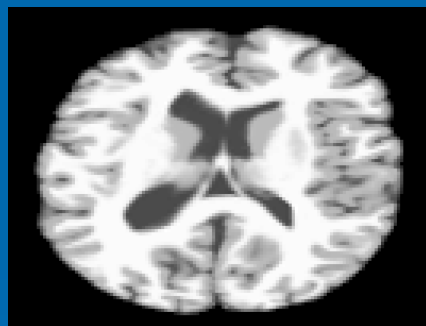


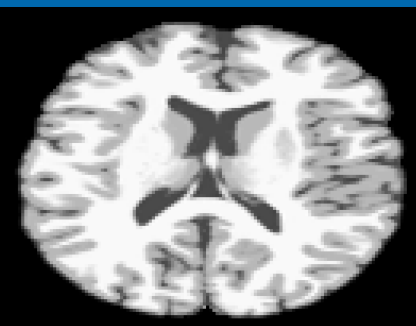
Image correction I: Experiment with phantom data

- Use MNI Template
- Create unbiased subject by TP-Spline warping
- Impose known bias fields & noise on subject
- Warps from template to biased subjects
- Use correcting and non-correcting warps

Subject image

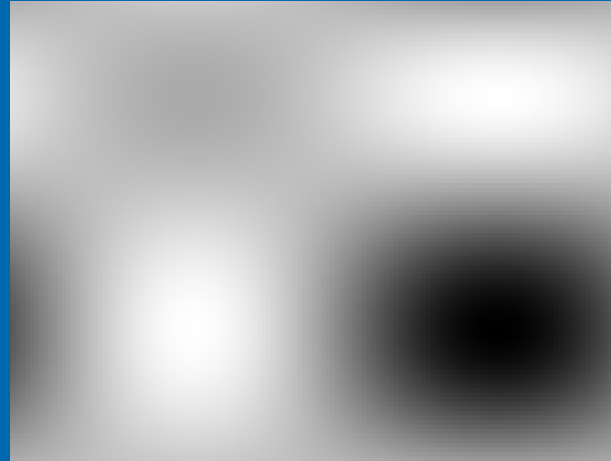


MNI Template

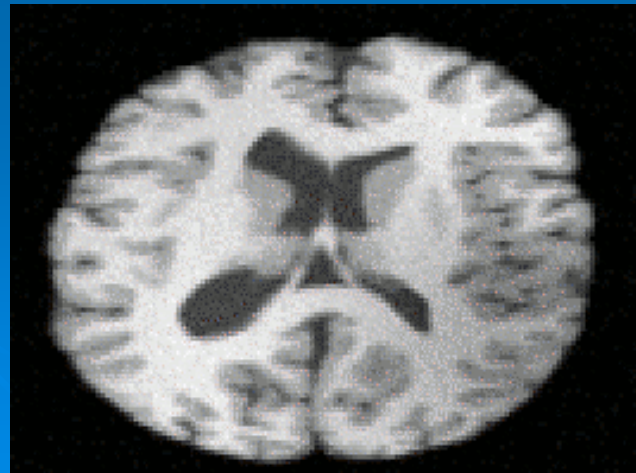


Phantom data: bias fields

- Impose bias field on unbiased subject
- Multiplicative field of magnitude $\pm 20\%$



Sinusoidal bias field



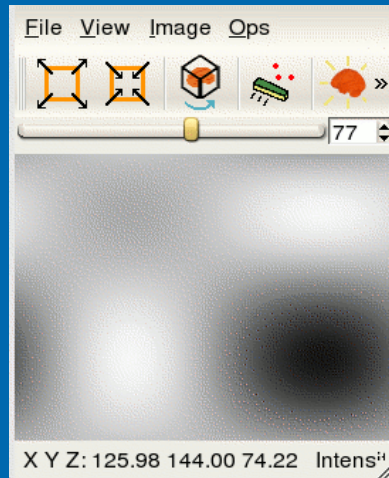
Biased image

Phantom data correction: measures of improvement

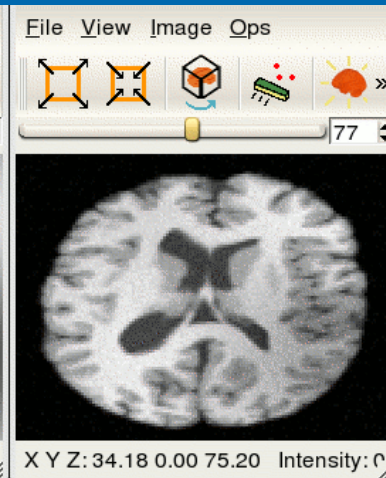
- With phantom data, make direct comparisons with known unbiased image
- Numerical comparisons use R^2 measure of image closeness and CV values of tissue variability
- Also make numerical R^2 comparisons with Jacobian images of unbiased warps

Phantom data correction: before (top) & after (bottom)

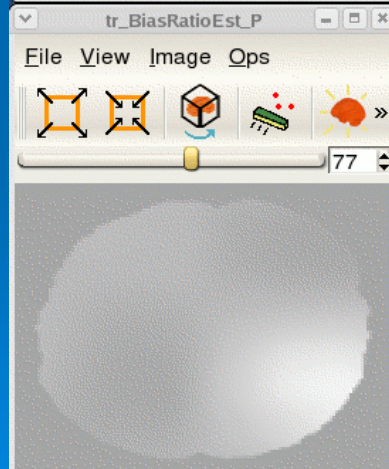
Bias field to be corrected



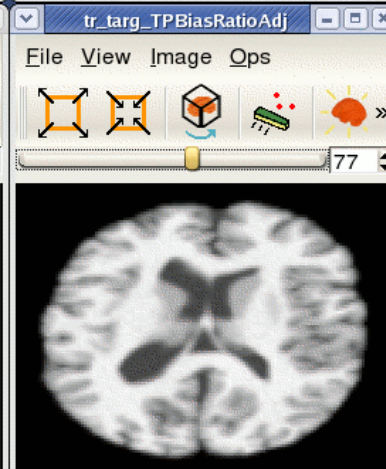
Biased image



Bias correction field

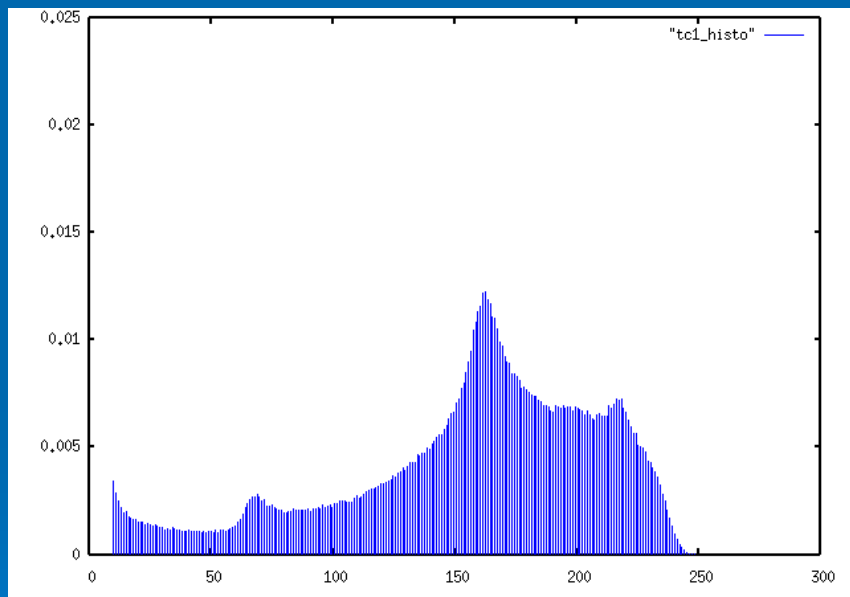


Corrected image

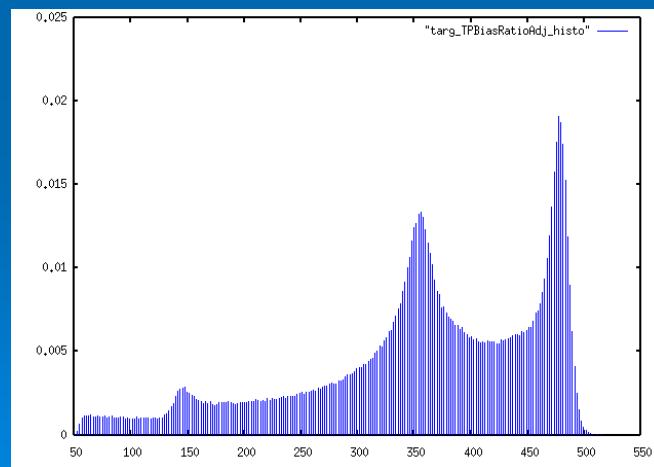
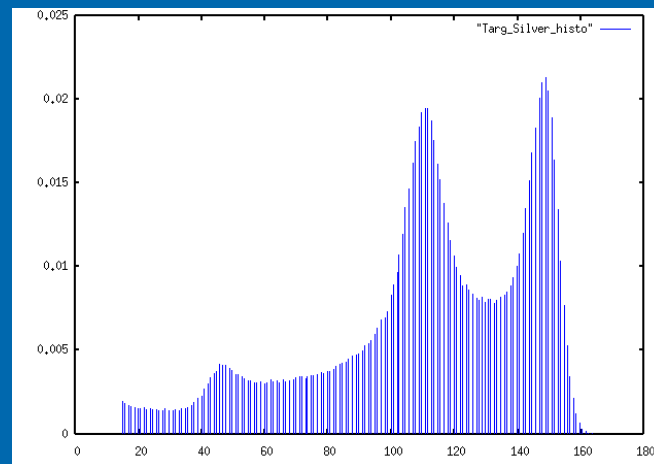


Phantom data correction: Comparison of image histograms

Uncorrected biased image



Unbiased image

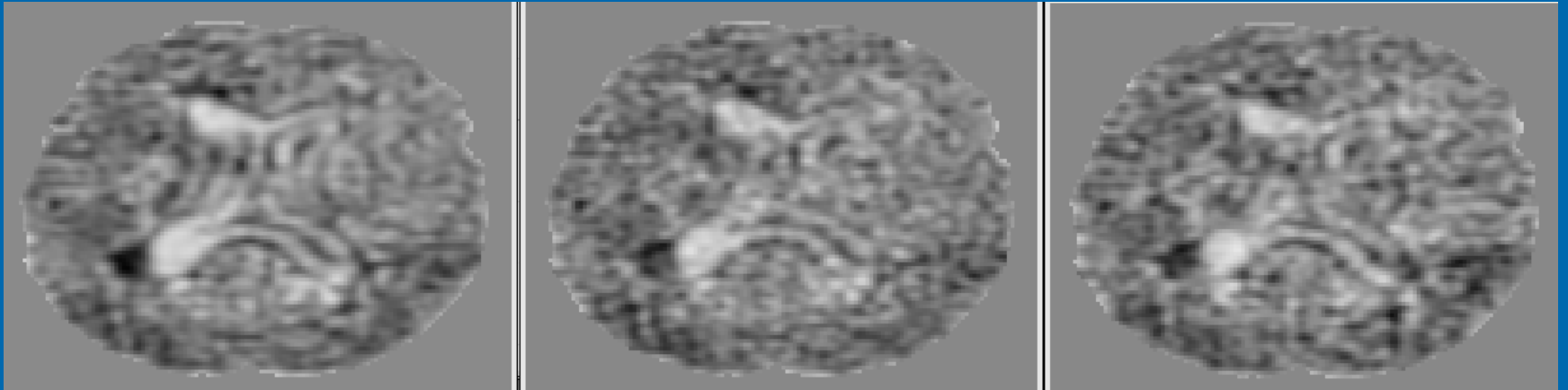


Corrected biased image

Phantom data correction: Jacobians 1

- Compare Jacobian images of correcting and non-correcting warps
- Use “ground truth” of warps from unbiased images
- Use numerical measures of accuracy

Phantom data correction: Jacobians 2



Reference

Correcting warp

Non-correcting

Phantom data correction:

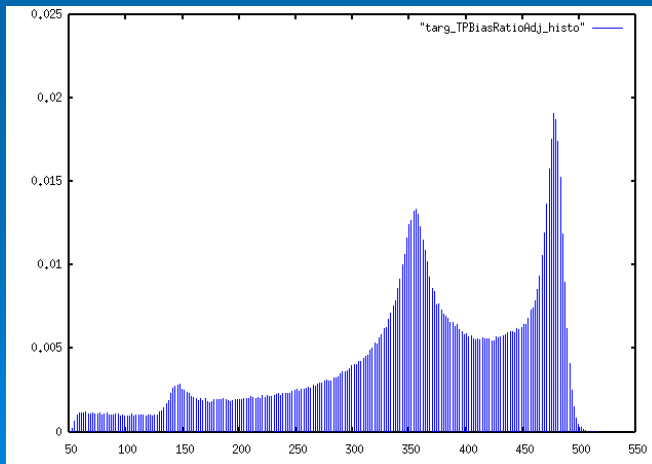
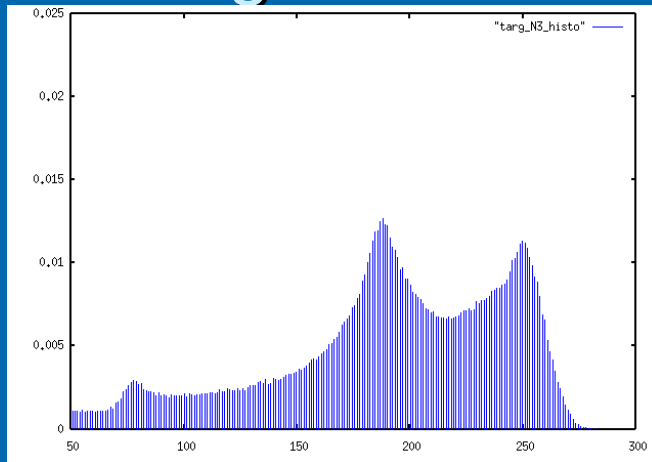
Distance measures to reference Jacobian

	Non-correcting	Correcting
Mean R^2	0.65	0.73
Std dev R^2	0.039	0.018

- 20 warps of template to biased images
- R^2 measure closeness of Jacobians to warps of unbiased images (max for Jacobians in practice ≈ 0.88)
- Higher R^2 is better!
- Std dev shows reduced Jacobian variability

Phantom data correction: Comparison with N3

Histograms



Jacobian R^2 values

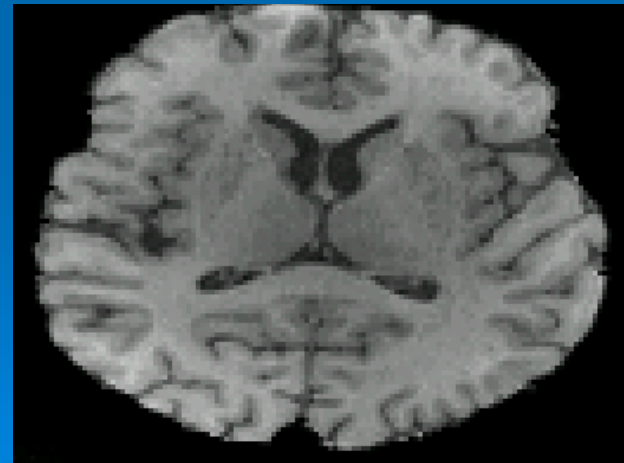
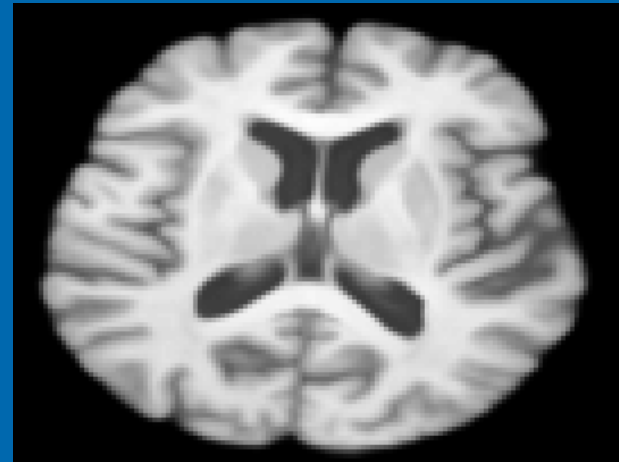
Non-Corr Warp	N3 + NC Warp	Corr Warp
0.65	0.68	0.73

R^2 measure of closeness to reference Jacobian is best for correcting warp

Top: N3 correction Bottom: warp correction

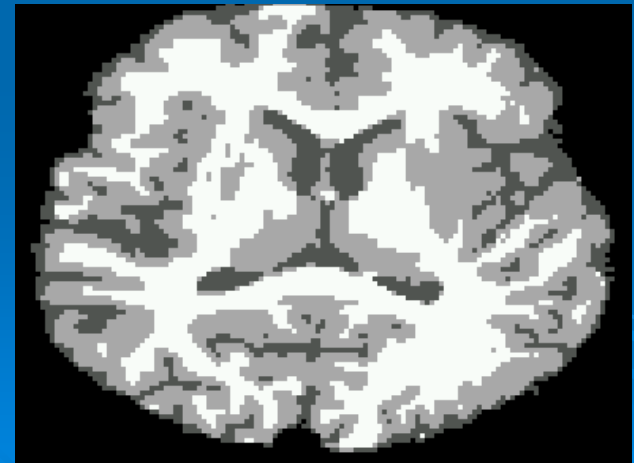
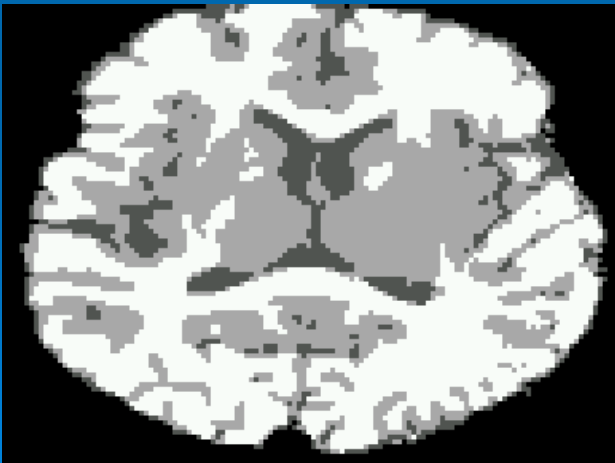
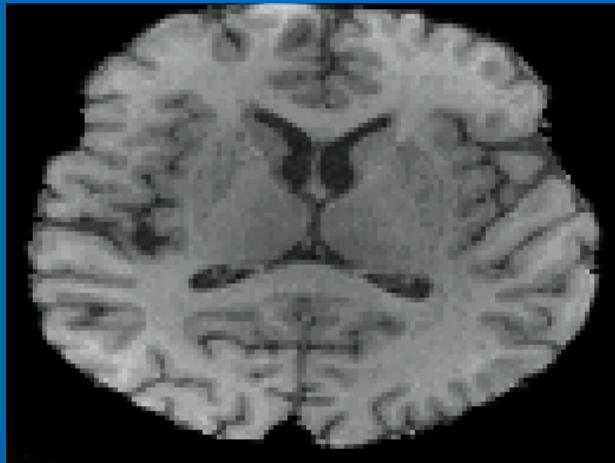
Image correction II: experiment with real data

- Apply correction during warping to real image with severe bias
- Use template derived from real study group
- With real data, rely on visual improvement of image, segmentation and histogram



Top: Template Bottom: subject

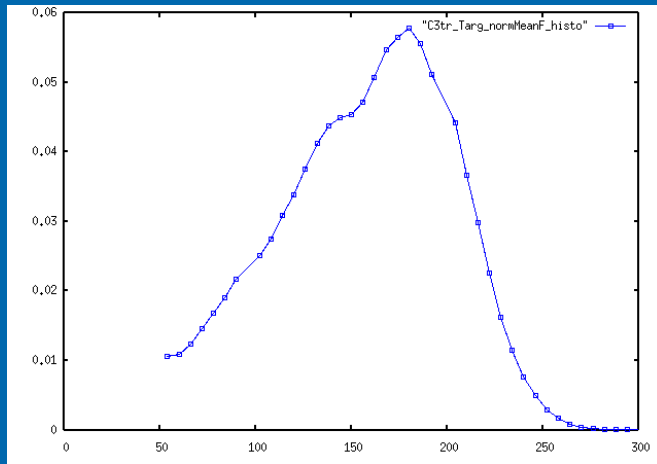
Real data correction: visual comparisons



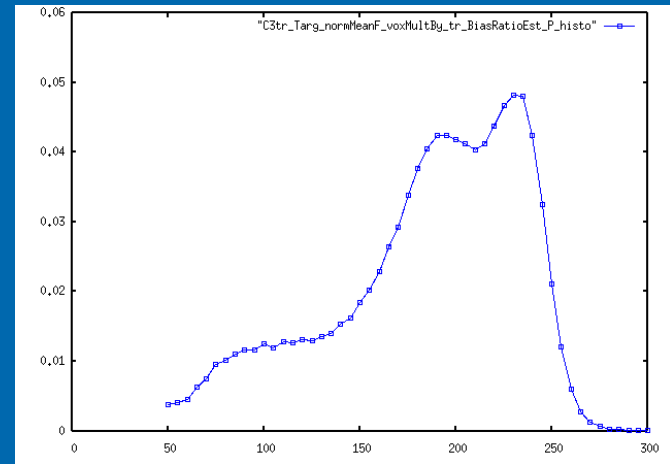
Uncorrected: image & segmentation

Warp-corrected

Real data correction: histograms



Uncorrected image



Corrected Image

Summary

Phantom Data

- Numerical and visual comparisons with known images & Jacobians
- Correcting warp is better than N3 and non-correcting
- Jacobian variability decreased in corr. warps

Real Data

- Visual comparison between corrected and uncorrected images and histograms
- Corrected images appear better