

# ANTs: A brief retrospective

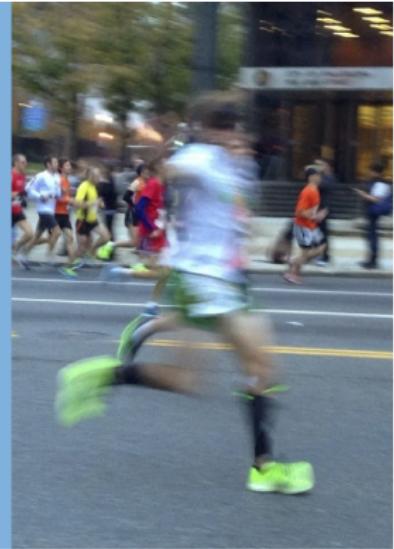
Nick Tustison

August 16, 2015

- 1 Founding developers**
- 2 ANTs lineage**
- 3 Major tools**
- 4 Putting it all together—the ANTs cortical thickness pipeline**
- 5 But, wait, there's more!**
- 6 But the best part is ...**
- 7 Joint label/intensity fusion**

# Founding developers

# Brian and Nick



# ANTs long term collaborators

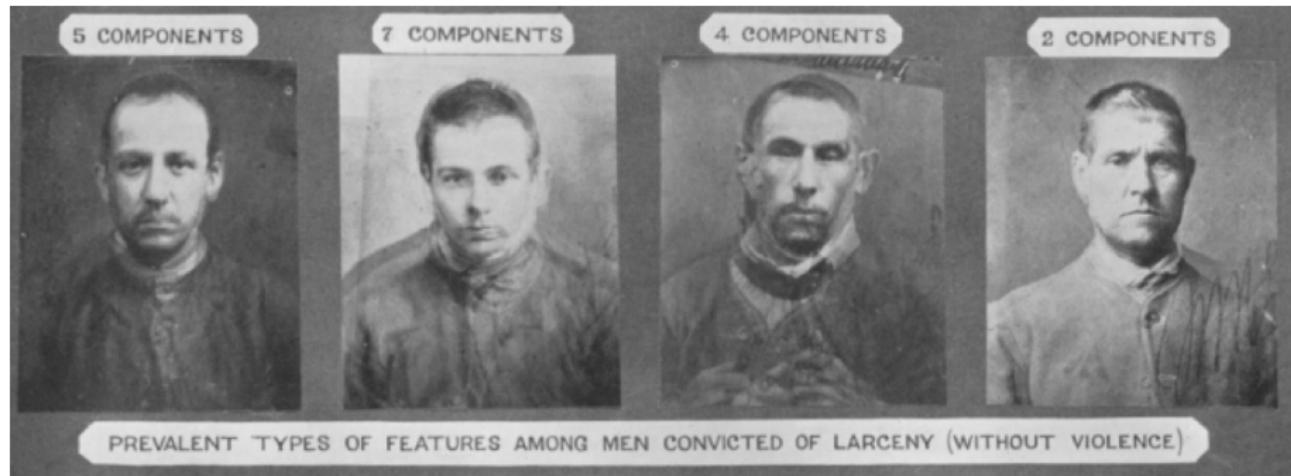


+ neurodebian, slicer, brainsfit, nipype, itk and more

# ANTs lineage

# Image mapping and perception: 1877

Francis Galton: *Can we see criminality in the face?*



*What about syphilis, mental illness?*

# Speaking of criminality...

*Can we say anything about the U.S. Congress?*



**Naive**

**Affine**

**SyN**

**Maybe they should have used ANTs?**

# Image mapping & biology: 1917

D'Arcy Thompson: *Comparison of related forms*

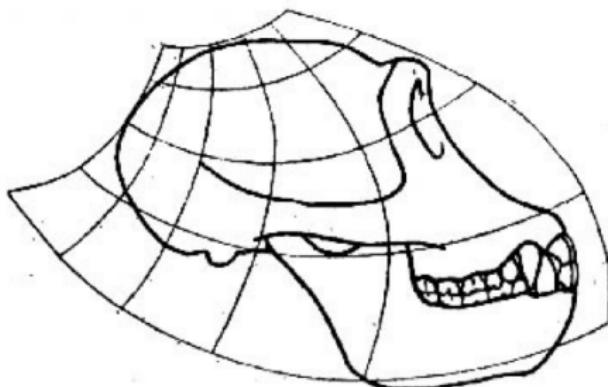


Fig. 550. Skull of chimpanzee.

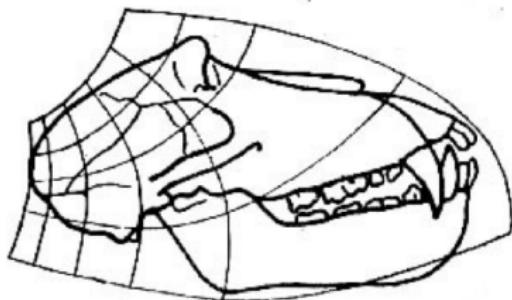
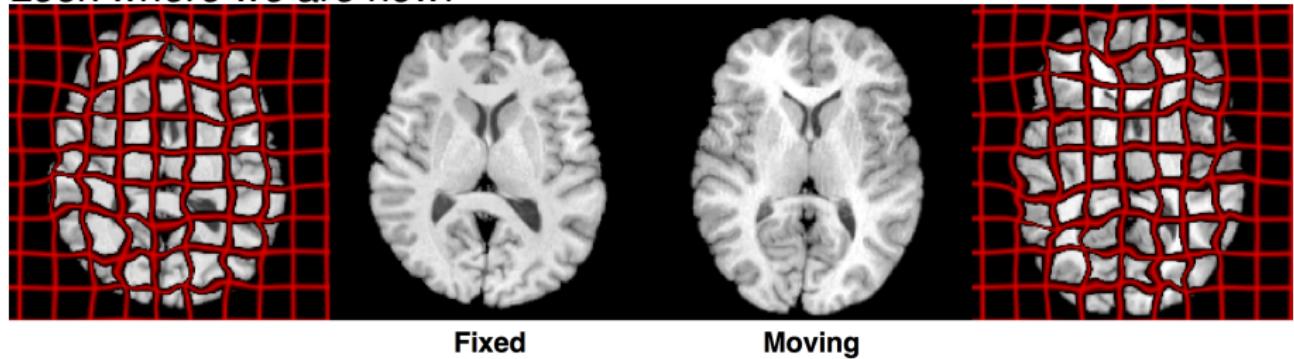


Fig. 551. Skull of baboon.

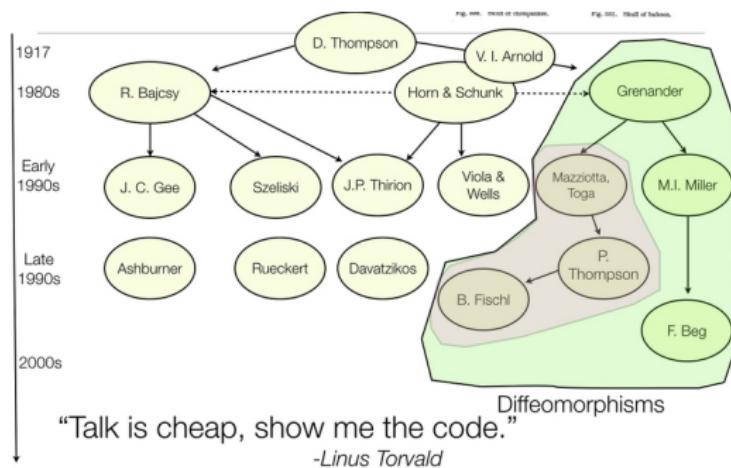
&gt;

# Image mapping & biology: Current

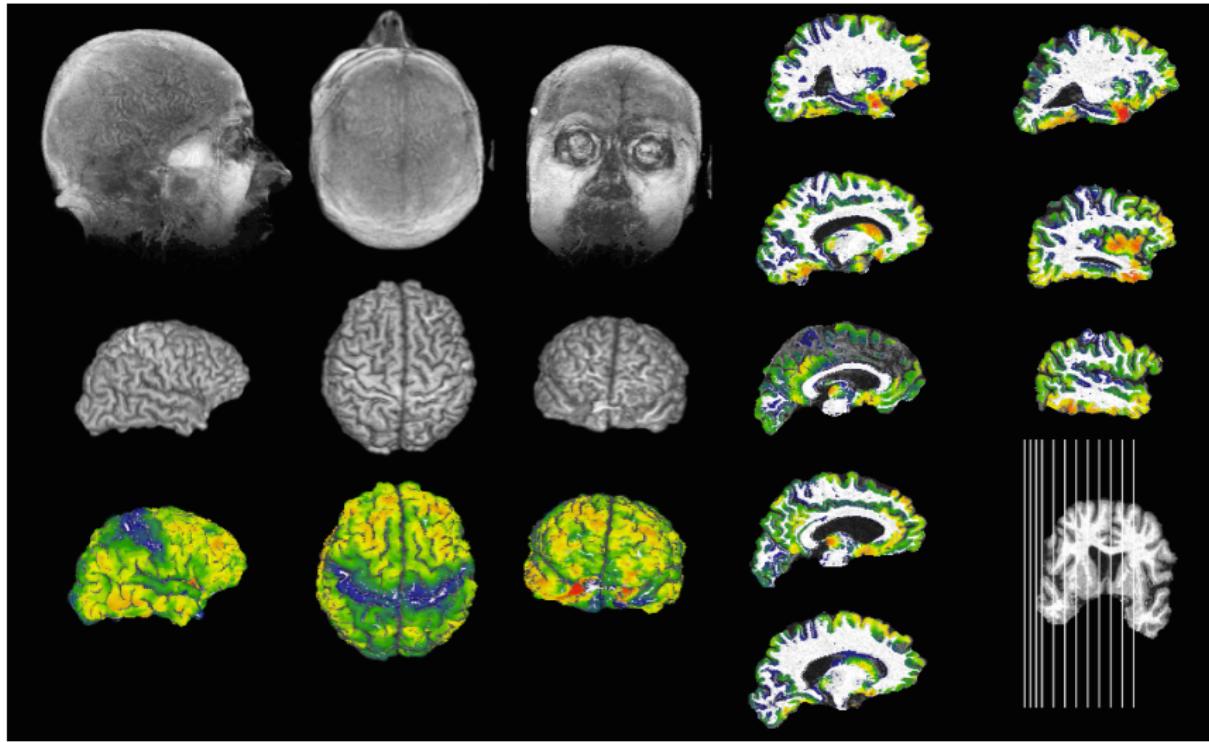
*Look where we are now!*



# ANTs family tree



# Initial scope



# Major tools

# Donoho?

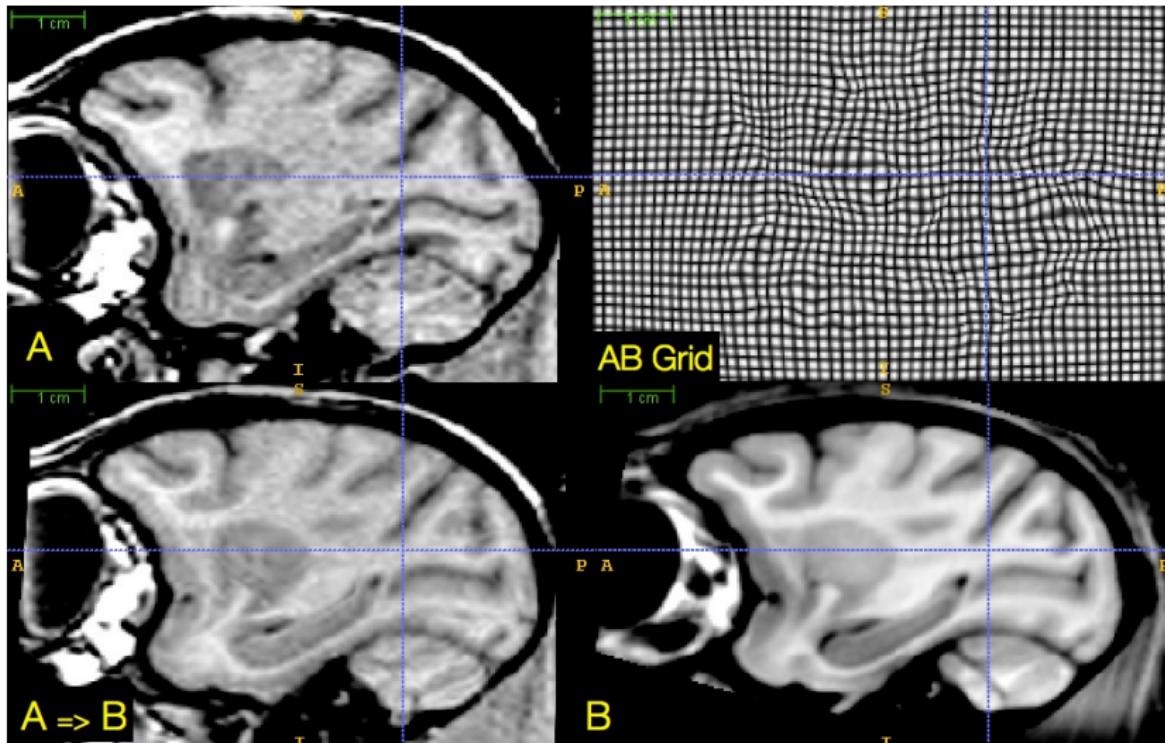
*“Papers are just advertisements for the science.”*

# Diffeomorphisms: Occam's razor modeling



*differentiable map with differentiable inverse*

# Diffeomorphisms: fine-grained and flexible maps



# Beyond original SyN

frontiers in  
**NEUROINFORMATICS**

ORIGINAL RESEARCH ARTICLE

published: 28 April 2014

doi: 10.3389/fninf.2014.00044



## The Insight ToolKit image registration framework

**Brian B. Avants<sup>1\*</sup>, Nicholas J. Tustison<sup>2</sup>, Michael Stauffer<sup>1</sup>, Gang Song<sup>1</sup>, Baohua Wu<sup>1</sup> and James C. Gee<sup>1</sup>**

<sup>1</sup> Penn Image Computing and Science Laboratory, Department of Radiology, University of Pennsylvania, Philadelphia, PA, USA

<sup>2</sup> Department of Radiology and Medical Imaging, University of Virginia, Charlottesville, VA, USA

frontiers in  
**NEUROINFORMATICS**

METHODS ARTICLE

published: 23 December 2013

doi: 10.3389/fninf.2013.00039



## Explicit B-spline regularization in diffeomorphic image registration

**Nicholas J. Tustison<sup>1\*</sup> and Brian B. Avants<sup>2</sup>**

# antsRegistration

```
$ antsRegistration --help
```

## COMMAND:

### antsRegistration

This program is a user-level registration application. It consists of a transform; an image metric; and iterative smoothing sigmas for each level. Note that dimensionality, output, convergence, shrink-factors and smoothing-sigma are mandatory.

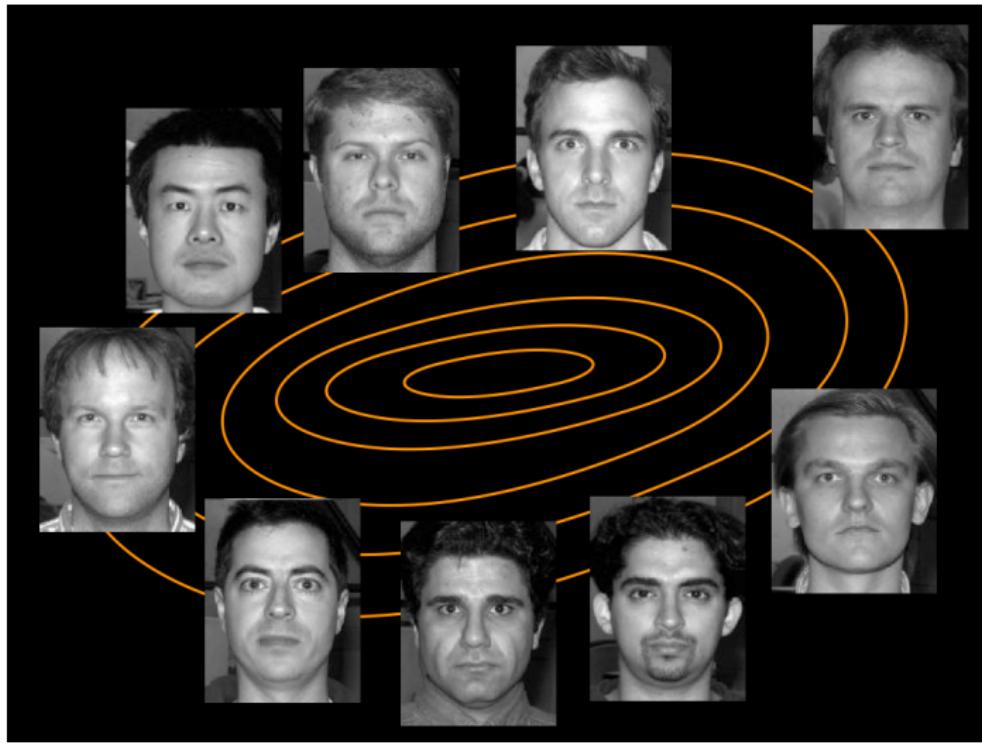
## OPTIONS:

### --version

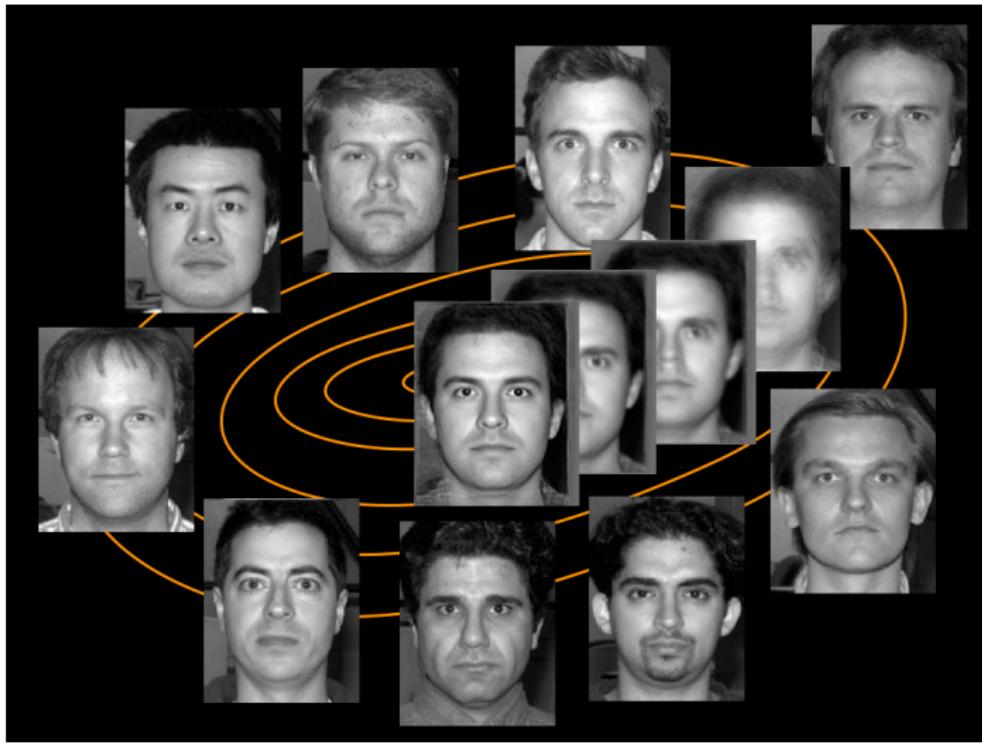
Get Version Information.

### -d, --dimensionality 2/3

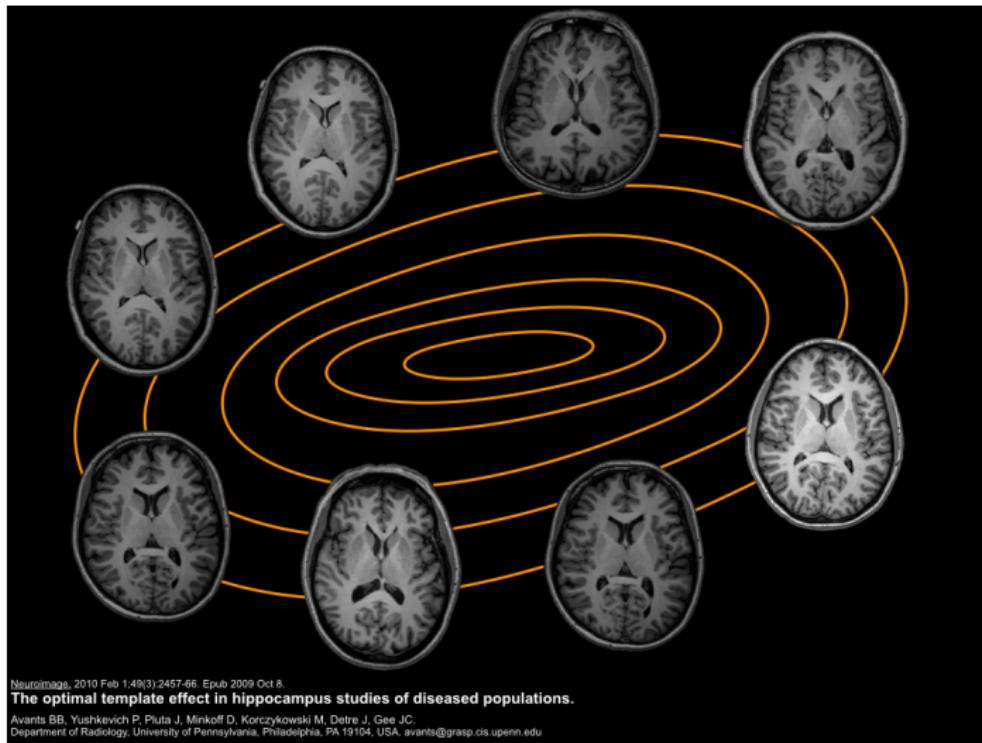
# Template building: creating the average Joe



# “Attractiveness” → mental processing?



# What about brains?



Neuroimage, 2010 Feb 1;49(3):2457-66. Epub 2009 Oct 8.

**The optimal template effect in hippocampus studies of diseased populations.**

Avants BB, Yushkevich P, Pluta J, Minkoff D, Korczykowski M, Detre J, Gee JC.

Department of Radiology, University of Pennsylvania, Philadelphia, PA 19104, USA. avants@grasp.cis.upenn.edu

# Templates facilitate computation



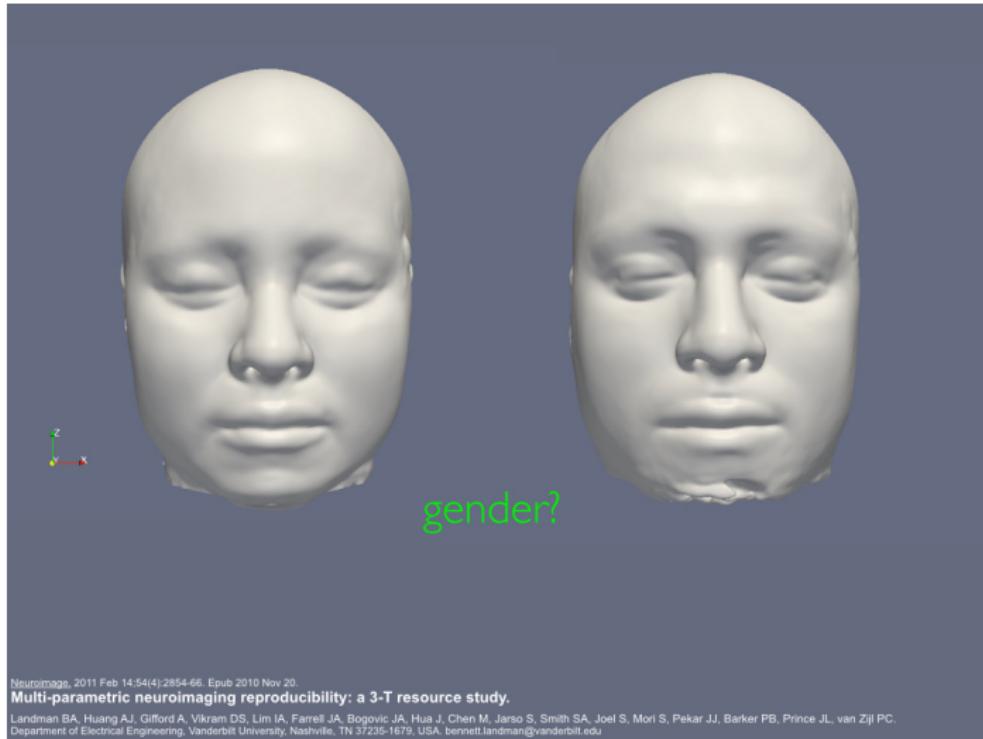
Neuroimage, 2010 Feb 1;49(3):2457-66. Epub 2009 Oct 8.

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Department of Radiology, University of Pennsylvania, Philadelphia, PA 19104, USA. avants@grasp.cis.upenn.edu

# Gender discernibility?



Neuroimage, 2011 Feb 14;54(4):2854-66. Epub 2010 Nov 20.

**Multi-parametric neuroimaging reproducibility: a 3-T resource study.**

Landman BA, Huang AJ, Gifford A, Vikram DS, Lim IA, Farrell JA, Bogovic JA, Hua J, Chen M, Jarso S, Smith SA, Joel S, Mori S, Pekar JJ, Barker PB, Prince JL, van Zijl PC.

Department of Electrical Engineering, Vanderbilt University, Nashville, TN 37235-1679, USA. bennett.landman@vanderbilt.edu

## antsMultivariateTemplateConstruction2.sh

```
$ antsMultivariateTemplateConstruction2.sh
```

Usage:

```
antsMultivariateTemplateConstruction2.sh -d ImageDimension -o
```

Compulsory arguments (minimal command line requires SGE/PBS cluster submission options):

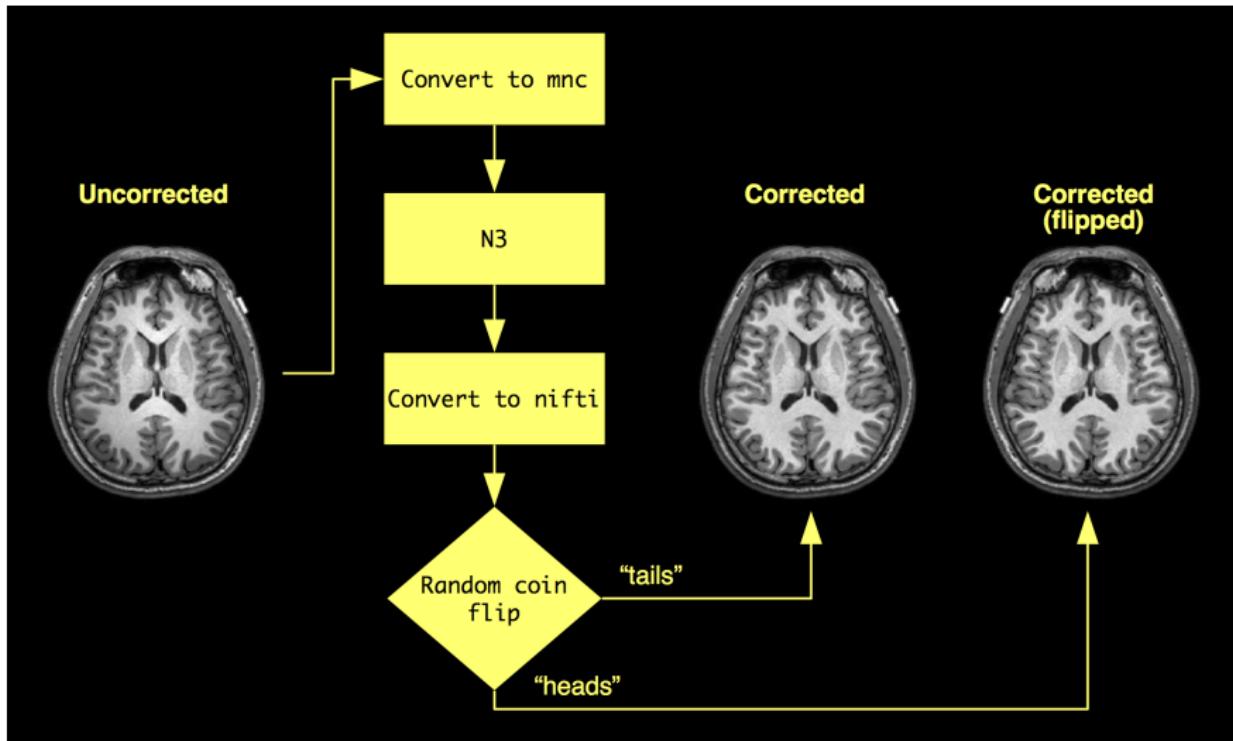
-d: ImageDimension: 2 or 3 (for 2 or 3 dimensional registration)

ImageDimension: 4 (for template generation of time-series data)

-o: OutputPrefix; A prefix that is prepended to all output files

<images> List of images in the current directory, eg \*\_t1.nii  
of the command. Optionally, one can specify a .csv file.

# N3 adoption issues



## N4BiasFieldCorrection

```
$ N4BiasFieldCorrection --help
```

### COMMAND:

#### **N4BiasFieldCorrection**

N4 is a variant of the popular N3 (nonparameteric nonrigid retrospective bias correction algorithm. Based on the corruption of the low frequency bias field can be modeled by a Gaussian, the basic algorithm iterates between deconvolving the intensity histogram of the intensities, and then spatially smoothing this histogram of the bias field itself. The modifications from and the original N3 algorithm are described in the following paper:  
J. C. Hata, S. Aylward, and R. H. Summers, "N4ITK: Improved N3 Bias Correction," IEEE Transactions on Medical Imaging, vol. 29(6):1310-1320, June 2010.

### OPTIONS:

# Atropos: flexible code base

“20+ years of development. *Show me the code!*”

## Initialization

- Gaussian
- Non-parametric
  - histogram Parzen windows
  - manifold Parzen windows

## Likelihood models

- Gaussian
- Non-parametric
  - histogram Parzen windows
  - manifold Parzen windows

# Atropos

## Prior models

- Markov random field
- Prior label images
- Prior probability images

## Miscellaneous

- Label geodesic/Euclidean propagation
- Outlier handling
- localized adaptive intensity handling

# Atropos

```
$ Atropos --help
```

## COMMAND:

### Atropos

A finite mixture modeling (FMM) segmentation approach specifying prior constraints. These prior constraints are defined by a prior label image, prior probability images (optional), and an MRF prior to enforce spatial smoothing of the labels. Atropos is built on top of FAST and SPM. Reference: Avants BB, Tustison NJ, Wu C, Gee JC. *Atropos: a source code multivariate framework for n-tissue segmentation*. Neuroinformatics. 2011 Dec;9(4):381-400.

## OPTIONS:

**-d, --image-dimensionality 2/3/4**

This option forces the image to be treated as a specific dimensionality. If this option is not specified, Atropos tries to infer the dimensionality from the image.

# Putting it all together—the ANTs cortical thickness pipeline

# Cortical thickness studies

Column1	Column2
Tetris-playing ability	chronic pancreatitis
Huntington's disease	obsessive-compulsive disorder
schizophrenia	ADHD
bipolar disorder	obesity
Alzheimer's disease	heritable depression
frontotemporal dementia	elderly depression
Parkinson's disease	age
Williams syndrome	gender
multiple sclerosis	handedness
autism	intelligence

# Basic components of the pipeline

- 1 template building (offline)

# Basic components of the pipeline

- 1** template building (offline)
- 2** brain extraction

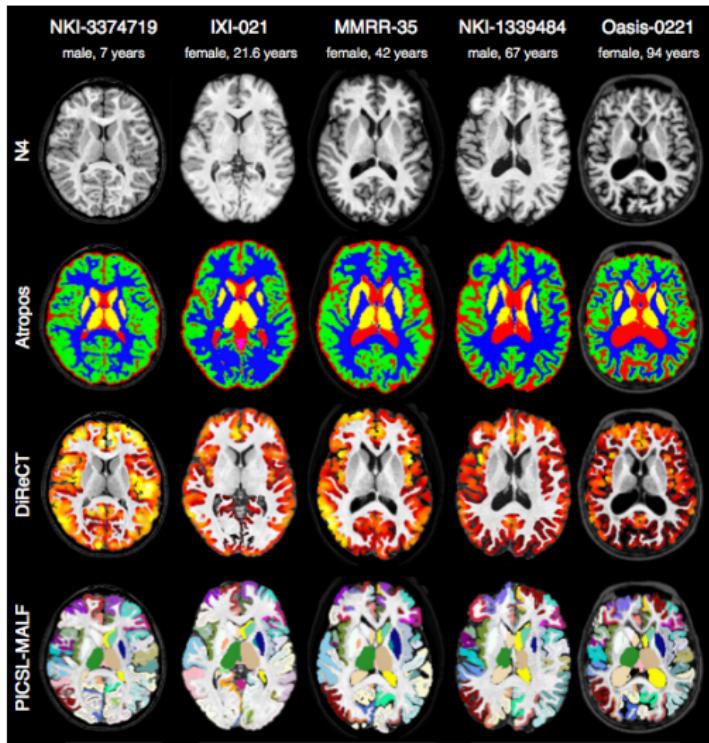
# Basic components of the pipeline

- 1** template building (offline)
- 2** brain extraction
- 3** cortical thickness estimation

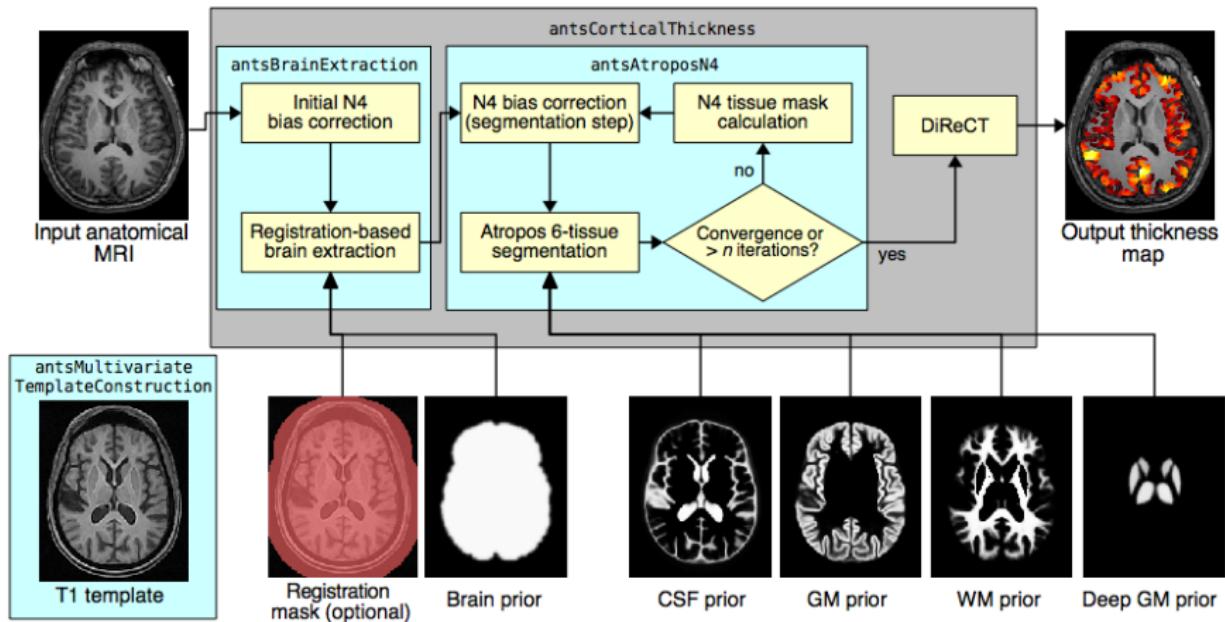
# Basic components of the pipeline

- 1** template building (offline)
- 2** brain extraction
- 3** cortical thickness estimation
- 4** cortical parcellation

# Sample results

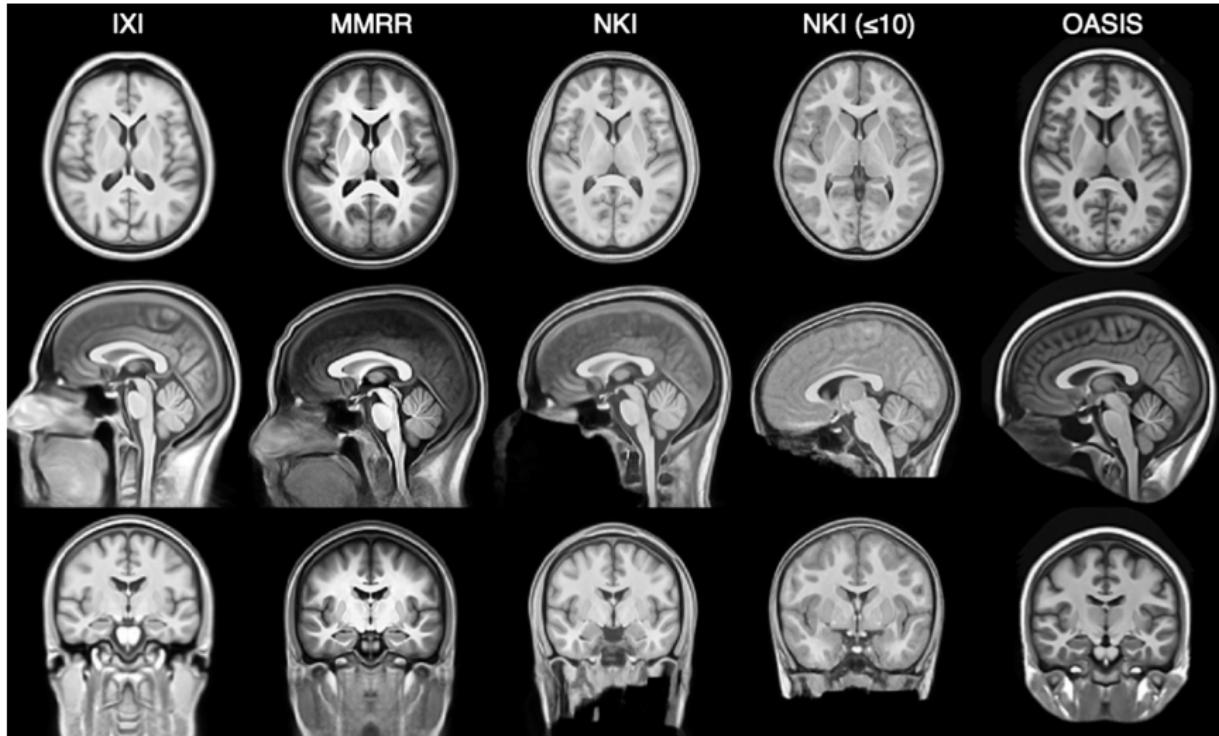


# The ANTs structural brain mapping workflow

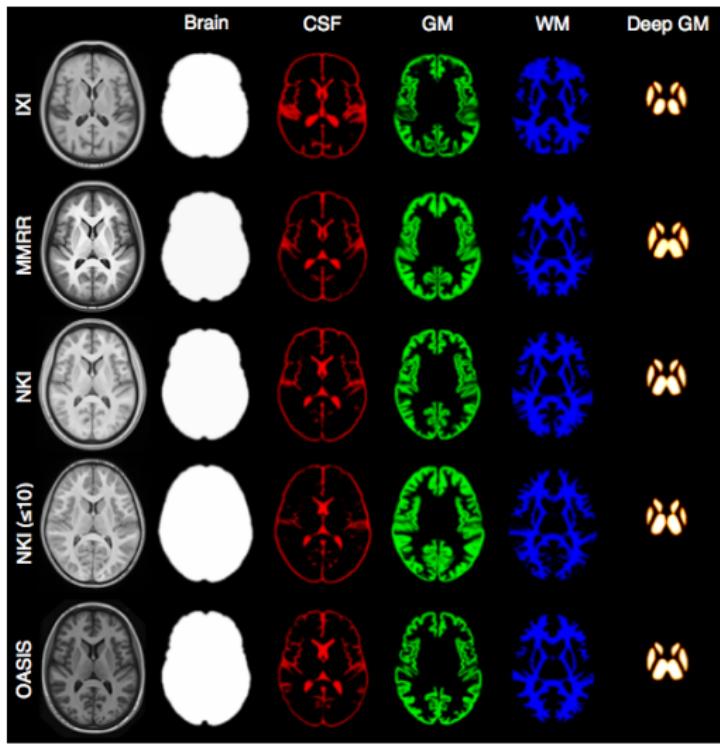


# Template building

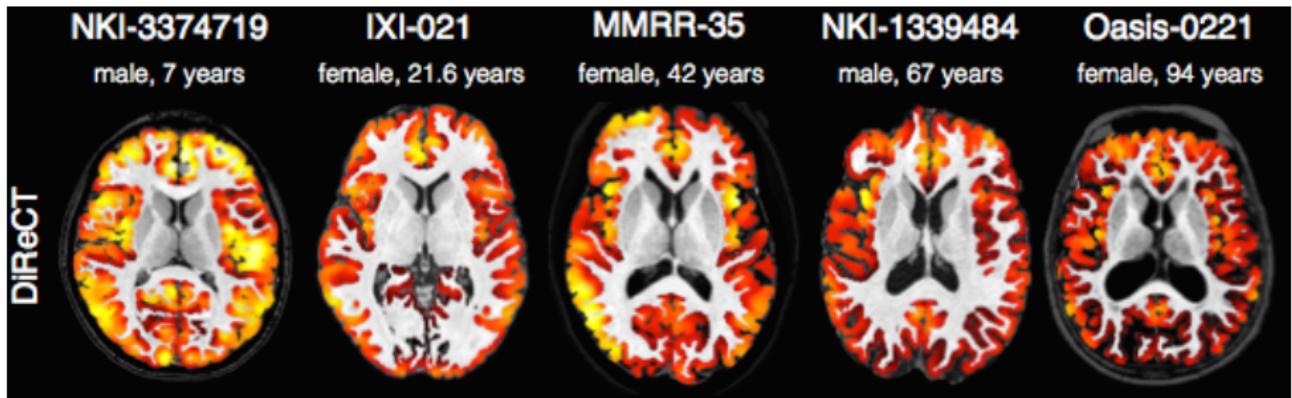
*Tailor data to your specific cohort*



# Template priors



# Cortical thickness estimation

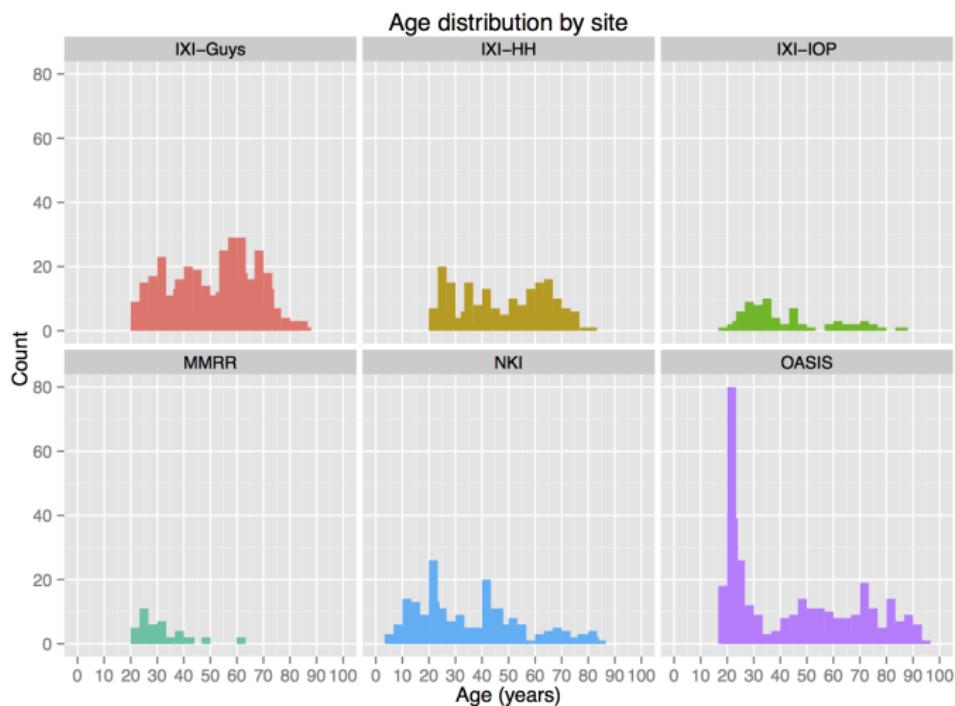


## *But without ground truth, how does one evaluate the pipeline?*

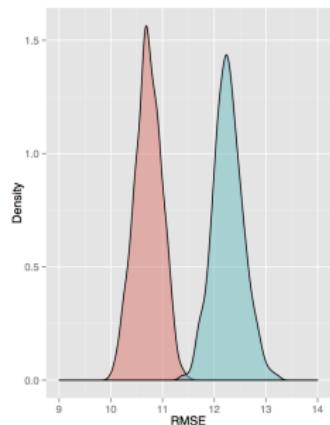
# Predict age and gender

$$AGE \sim VOLUME + GENDER + \sum_{i=1}^{62} T(DKT_i)$$

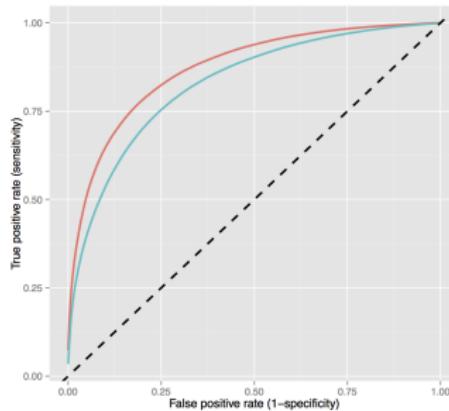
# Open science principles



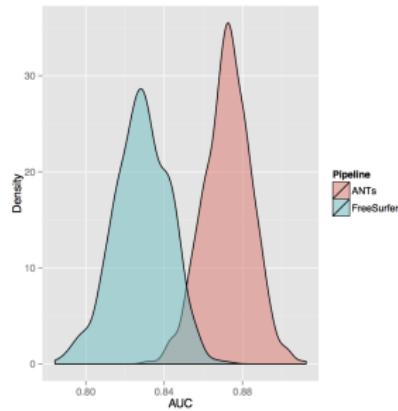
# Prediction from cortical thickness data



Age



Gender



# Age prediction per site

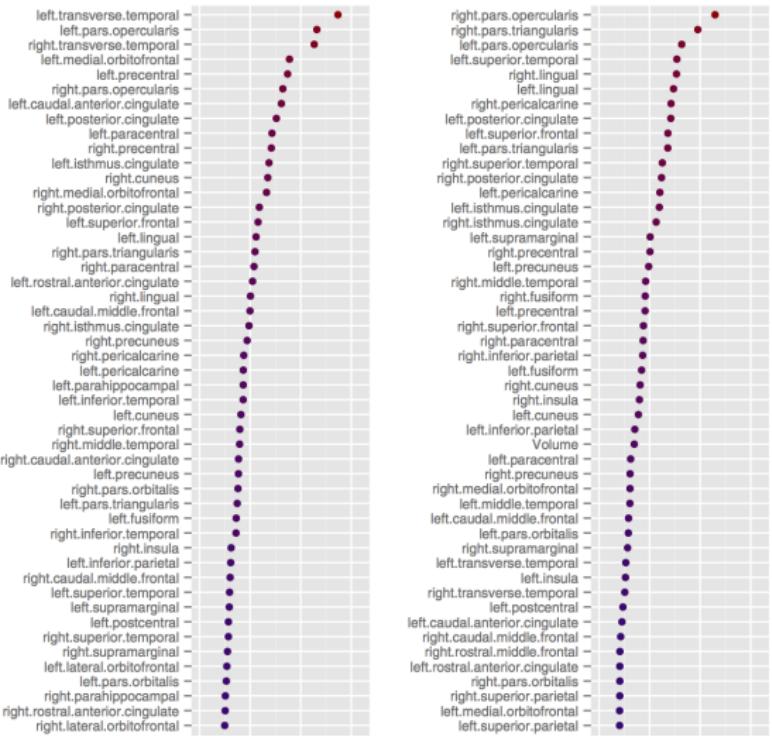
**Table 3**

Mean RMSE for age prediction in years.

	Linear model	Random forest
ANTs (combined)	10.7	10.2
FreeSurfer (combined)	12.3	11.9
ANTs (IXI)	9.3	8.6
FreeSurfer (IXI)	12.3	11.7
ANTs (NKI)	NA <sup>a</sup>	10.9
FreeSurfer (NKI)	NA <sup>a</sup>	13.3
ANTs (OASIS)	15.0	12.4
FreeSurfer (OASIS)	15.0	11.4

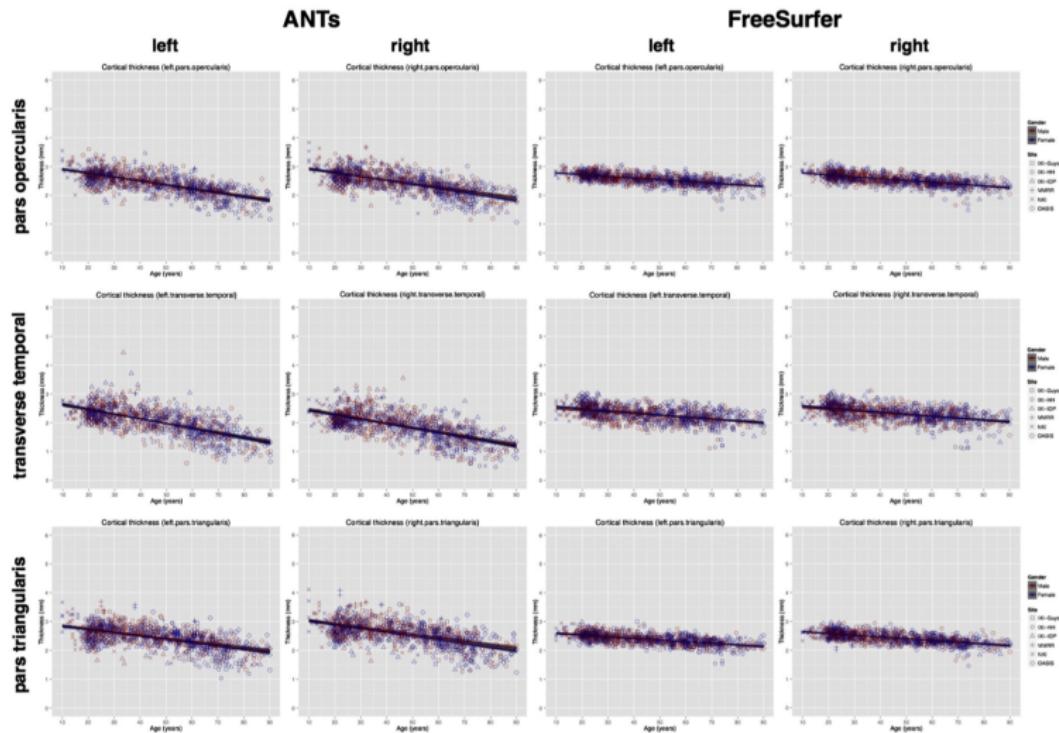
<sup>a</sup> Fitting error.

# Regional importance comparison



ANTs (left) vs. FreeSurfer (right)

# Regional measurements



# But, wait, there's more!

## Data availability

- “Hey, can I have the FreeSurfer measurements for the entorhinal cortex?” Sure, why not?

## Data availability

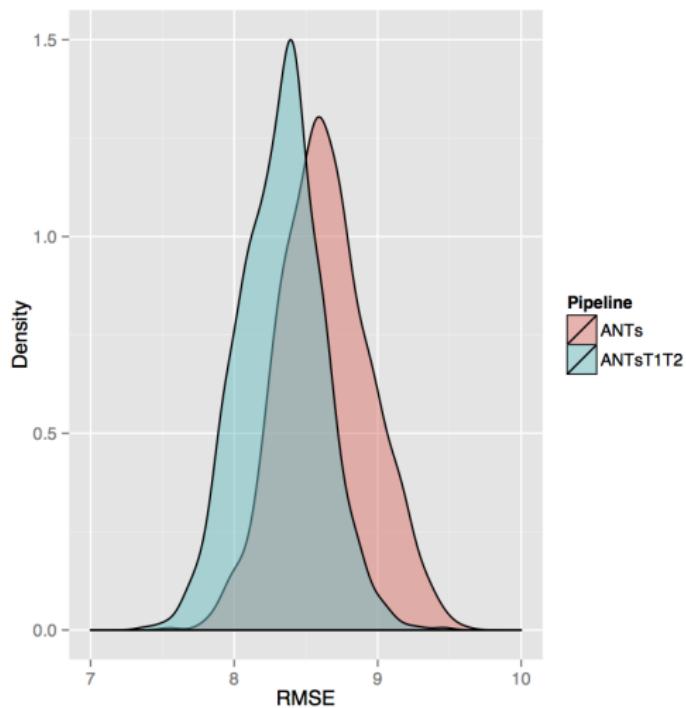
- “Hey, can I have the FreeSurfer measurements for the entorhinal cortex?” Sure, why not?
- “I was wondering if you would make available the CT in each ROI for each subject. . .” Sure, why not? Would you also like the surface areas and volumes?

## Data availability

- “*Hey, can I have the FreeSurfer measurements for the entorhinal cortex?*” Sure, why not?
- “*I was wondering if you would make available the CT in each ROI for each subject. . .*” Sure, why not? Would you also like the surface areas and volumes?
- “*Can I have one or more of the templates that you used for your study?*” Would you like the priors as well?

# What about using both the T1 & T2?

# ANTs tools are multivariate

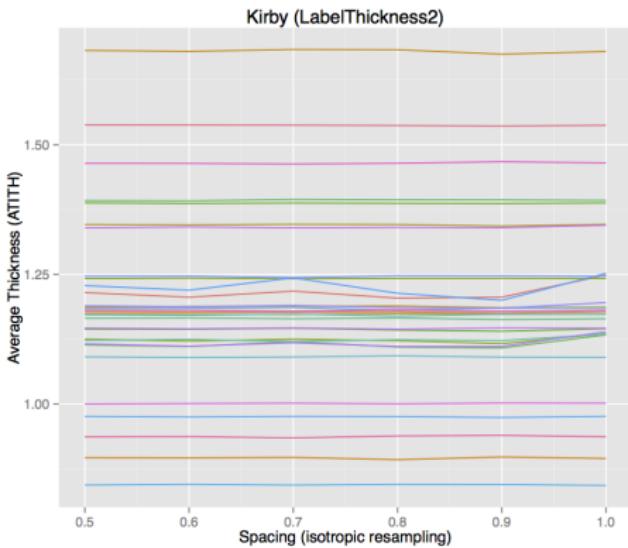
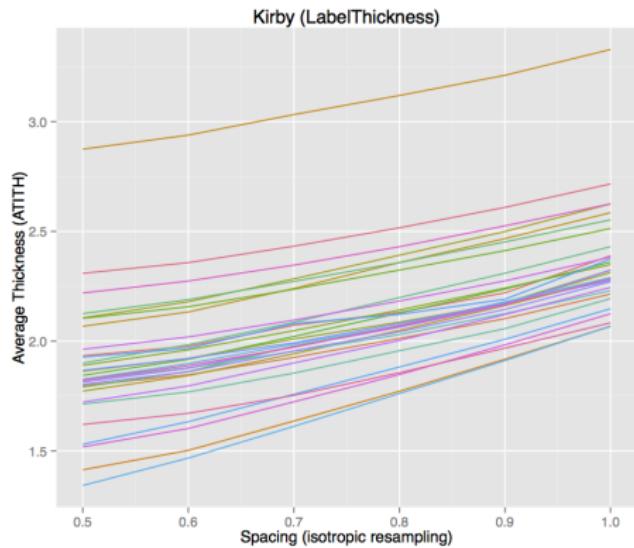


# Arno-thick-in-the-head (ATITH)

*What if we made a crude estimate of the cortical thickness?*

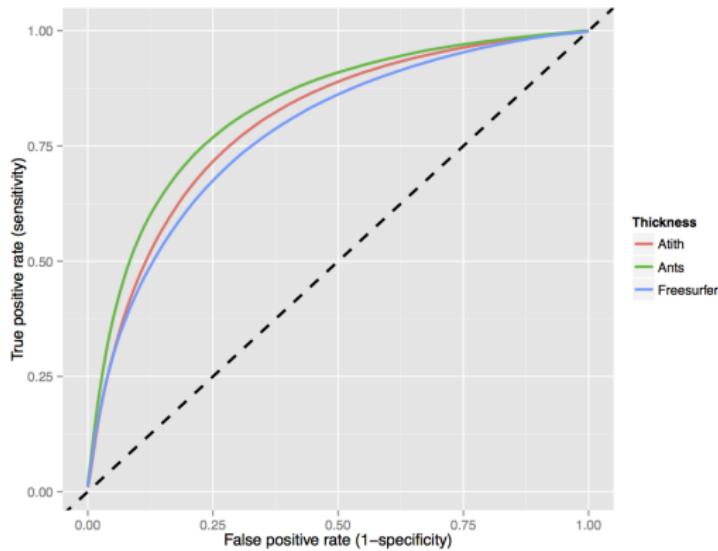
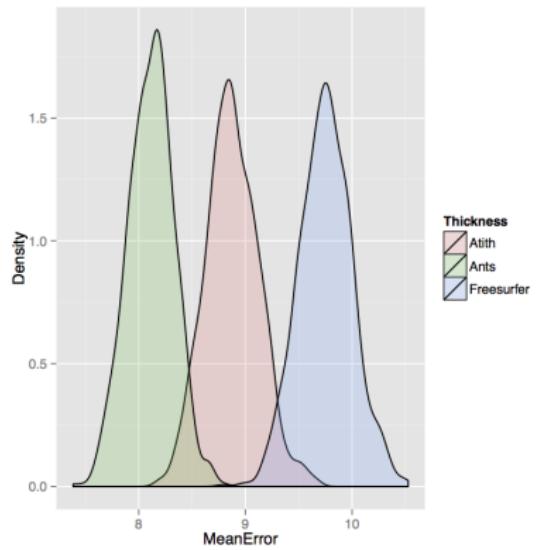
$$\text{thickness}_{ROI} = \frac{\text{volume}_{ROI}}{\text{area}_{ROI}}$$

# Make sure you estimate the surface area correctly!



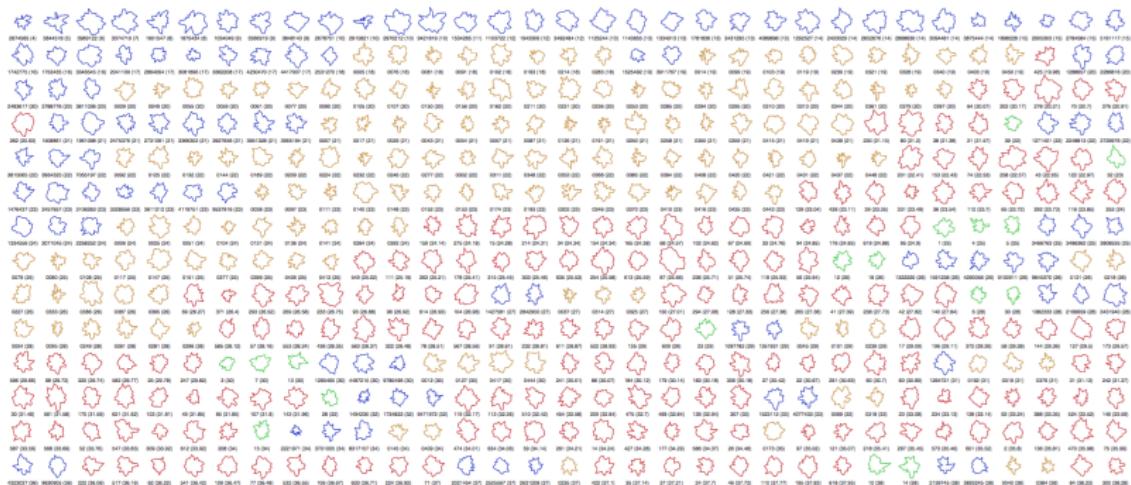
# So how does ATITH compare with ANTs, FS?

# Prediction from cortical thickness data



# Brain constellation maps

## Brain Constellation Map of Thickness Residuals



# *Does denoising help?*

# Contribution from Jose

```
$ DenoiseImage
```

## COMMAND:

```
DenoiseImage
```

Denoise an image using a spatially adaptive filter (.

Manjon, P. Coupe, Luis Marti-Bonmati, D. L. Collins

Non-Local Means Denoising of MR Images With Spatial

Journal of Magnetic Resonance Imaging, 31:192-203, .

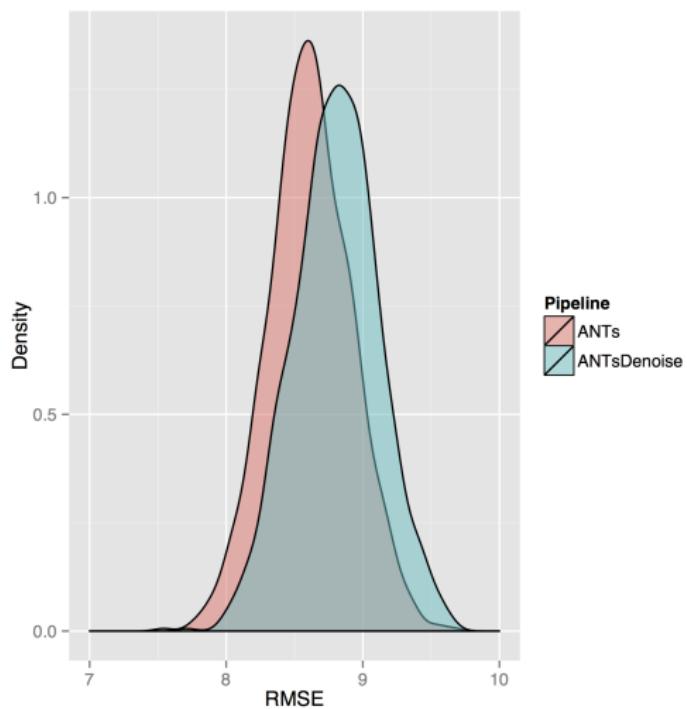
## OPTIONS:

```
-d, --image-dimensionality 2/3/4
```

This option forces the image to be treated as a specific dimensionality. If not specified, the program tries to infer the dimensionality of the image.

```
-i, --input-image inputImageFilename
```

# Does denoising help?



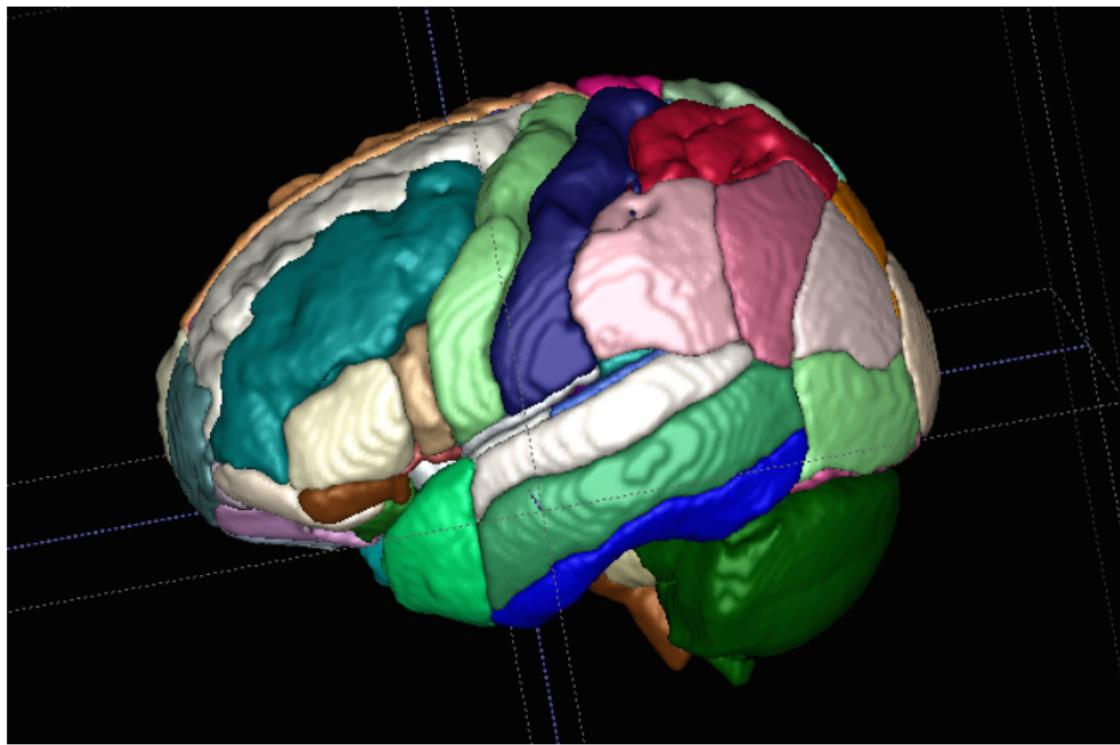
**But the best part is ...**

# it is absolutely free!

```
 ${ANTSPATH}/antsCorticalThickness.sh \
 -a IXI/T1/IXI002-Guys-0828-T1.nii.gz \
 -e IXI/template/T_template0.nii.gz \
 -m IXI/template/T_template0ProbabilityMask.nii.gz \
 -f IXI/template/T_template0ExtractionMask.nii.gz \
 -p IXI/template/Priors/priors%d.nii.gz \
 -o IXI/ANTSResults/IXI002-Guys-0828-
```

# Joint label/intensity fusion

# Multi-atlas labeling

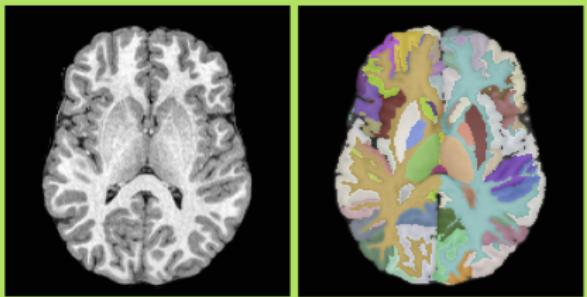


# Multi-atlas segmentation

## Joint label fusion



Atlases  
(grayscale + segmentation)



Target image

Target segmentation

# Multi-atlas 2012 results

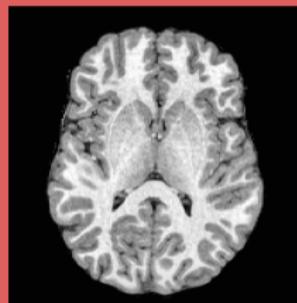
Overall Rank †	Repro. Rank‡	Team Name	Mean DSC Overall	Mean DSC Cortical	Mean DSC Non-Cortical
1	1	PICSL_BC	0.7654	0.7388	0.8377
2	2	NonLocalSTAPLE	0.7581	0.7318	0.8296
3	3	MALP_EM	0.7576	0.7328	0.8252
4	4	PICSL_Joint	0.7499	0.7216	0.8271
5	6	MAPER	0.7413	0.7144	0.8144
6	7	STEPS	0.7372	0.7107	0.8095
7	5	SpatialSTAPLE	0.7372	0.7093	0.8130
8	9	CIS_JHU	0.7357	0.7131	0.7971
9	8	CRL_Weighted_STAPLE ANTS+Baloo	0.7344	0.7122	0.7950
10	10	CRL_Weighted_STAPLE ANTS	0.7308	0.7066	0.7966

# New work: joint intensity fusion

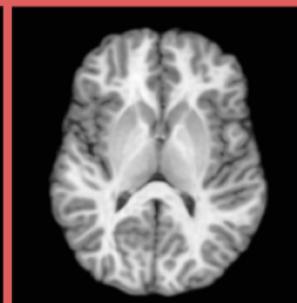
## Joint intensity fusion



Atlases  
(grayscale only)



Target image



Target fusion image