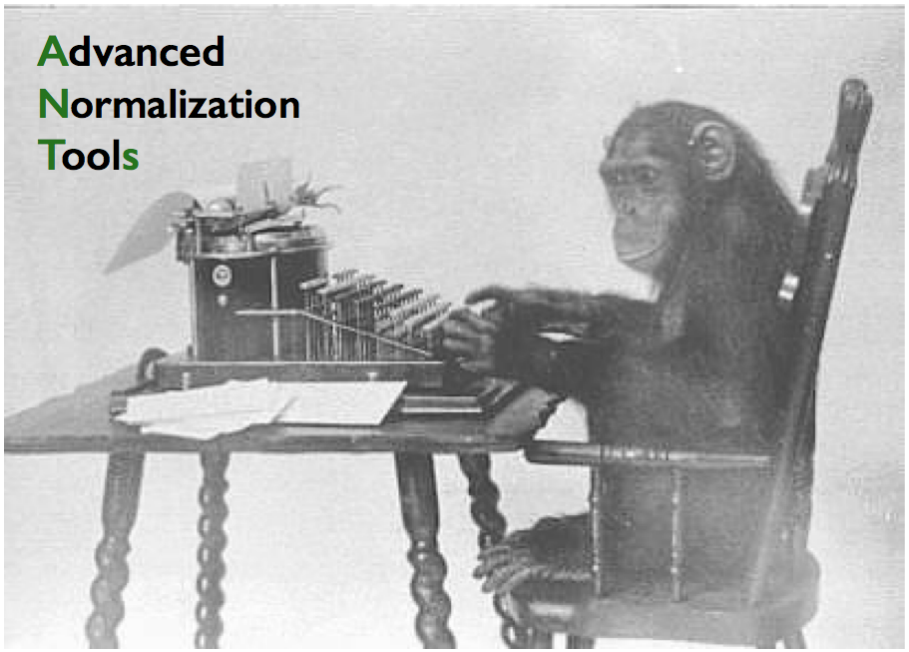
“Dr. Tustison (UVA) presentation”

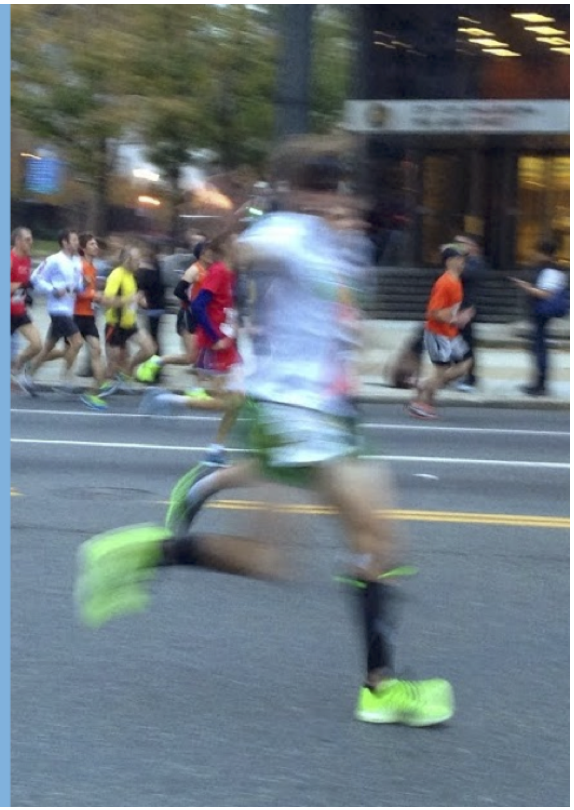
Nick Tustison

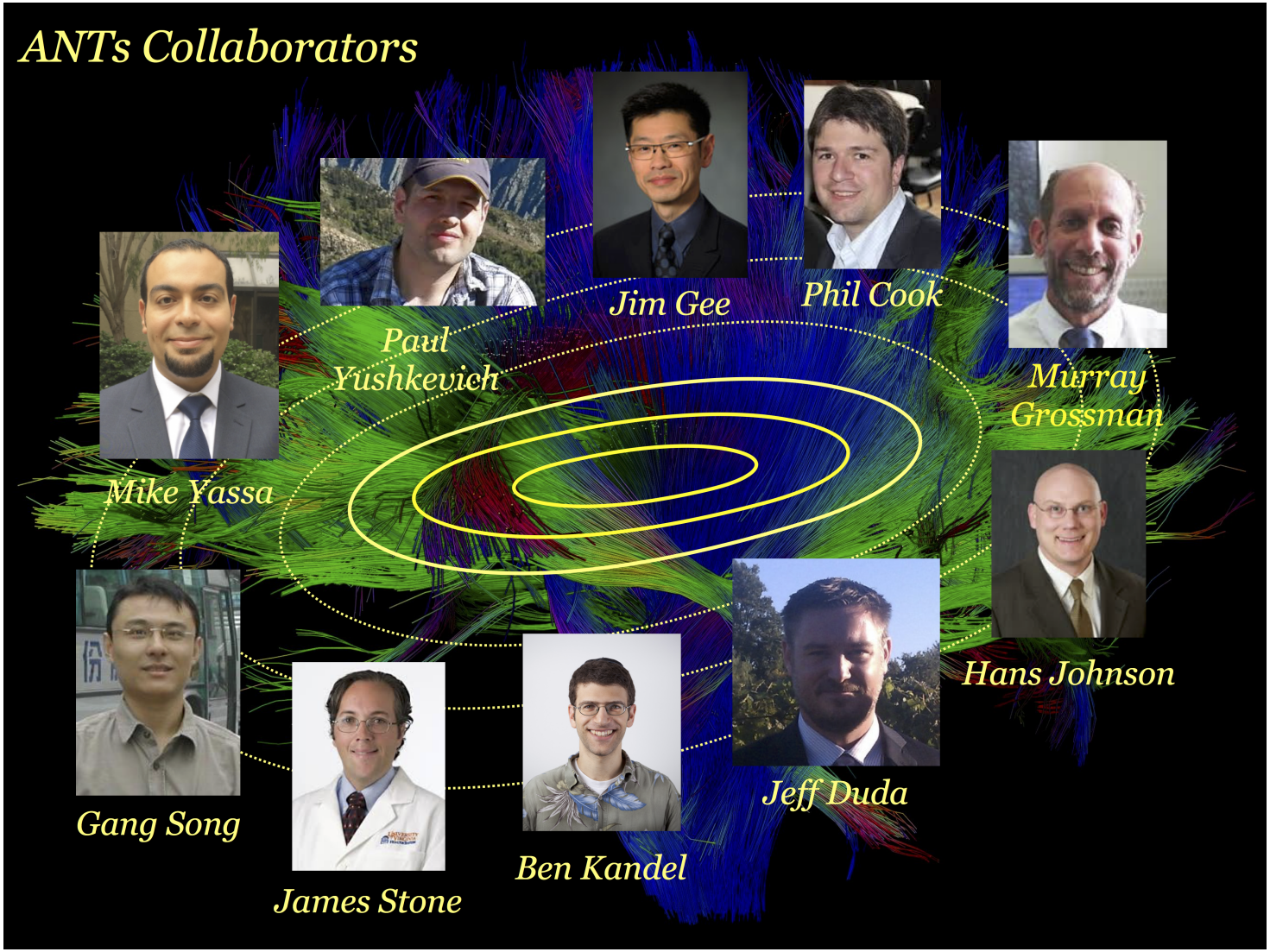
University of Virginia



Developers and collaborators

Founders: Brian and Nick





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

Why would you care?

Software for medical image analysis

- FSL
- SPM
- FreeSurfer
- MIPAV
- AFNI
- Slicer, Elastix, SimpleITK, ANTs $\longleftrightarrow$ Insight Toolkit
- Many more at idoimaging.com

International competitions

- Klein 2009: MRI brain registration
- EMPIRE 2010: CT lung registration
- Multi-Atlas Label Challenge 2012: MRI brain registration and segmentation
- SATA Challenge 2013: MRI cardiac and canine hind leg registration
- BRATS 2013: Multi-modal MRI brain segmentation
- STACOM 2014 MoCo Challenge: MRI cardiac motion estimation

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*

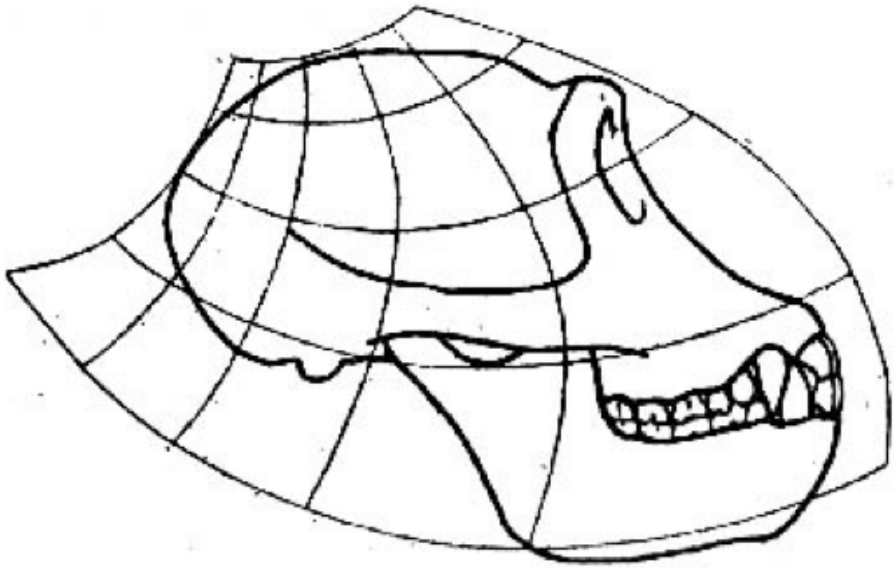


Fig. 550. Skull of chimpanzee.

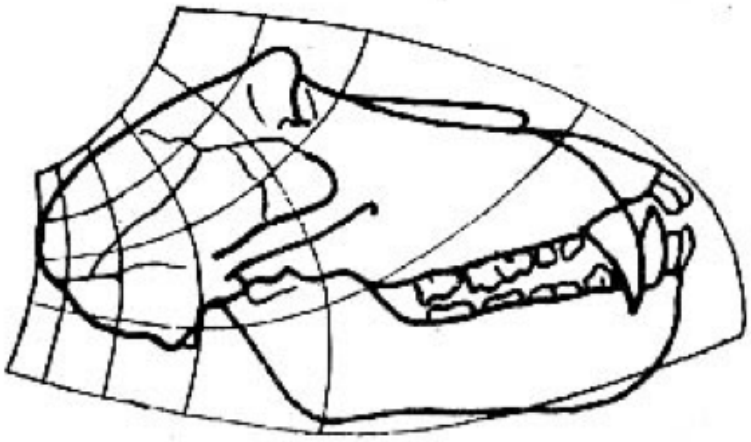
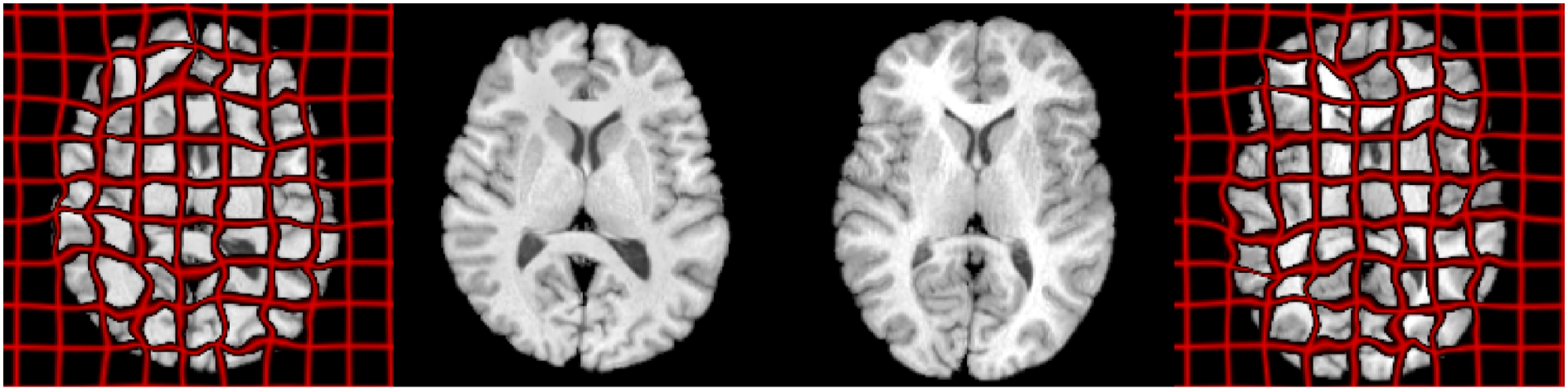


Fig. 551. Skull of baboon.

>

Image mapping & biology: Current

Look where we are now!

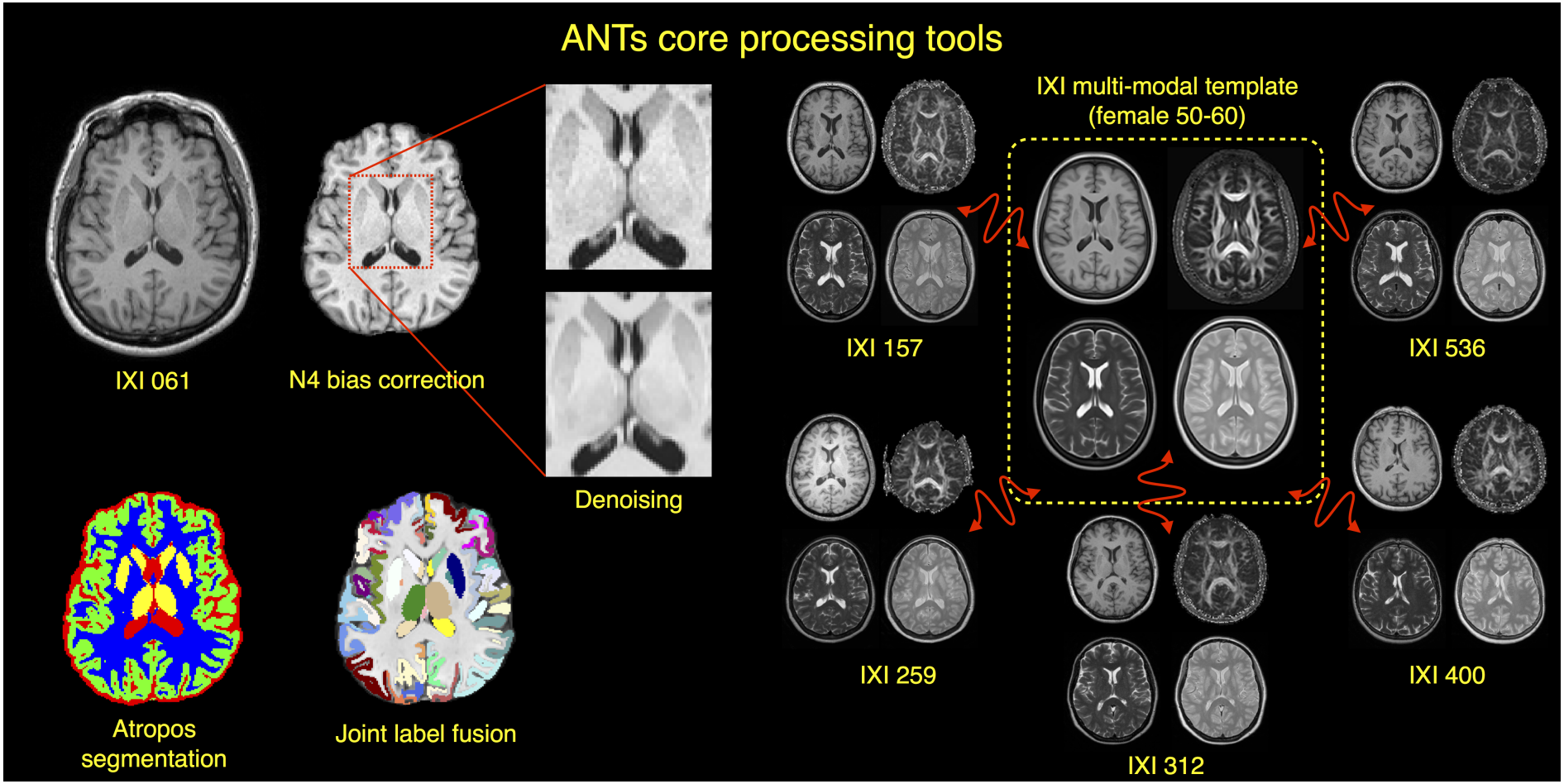


Major ANTs utilities

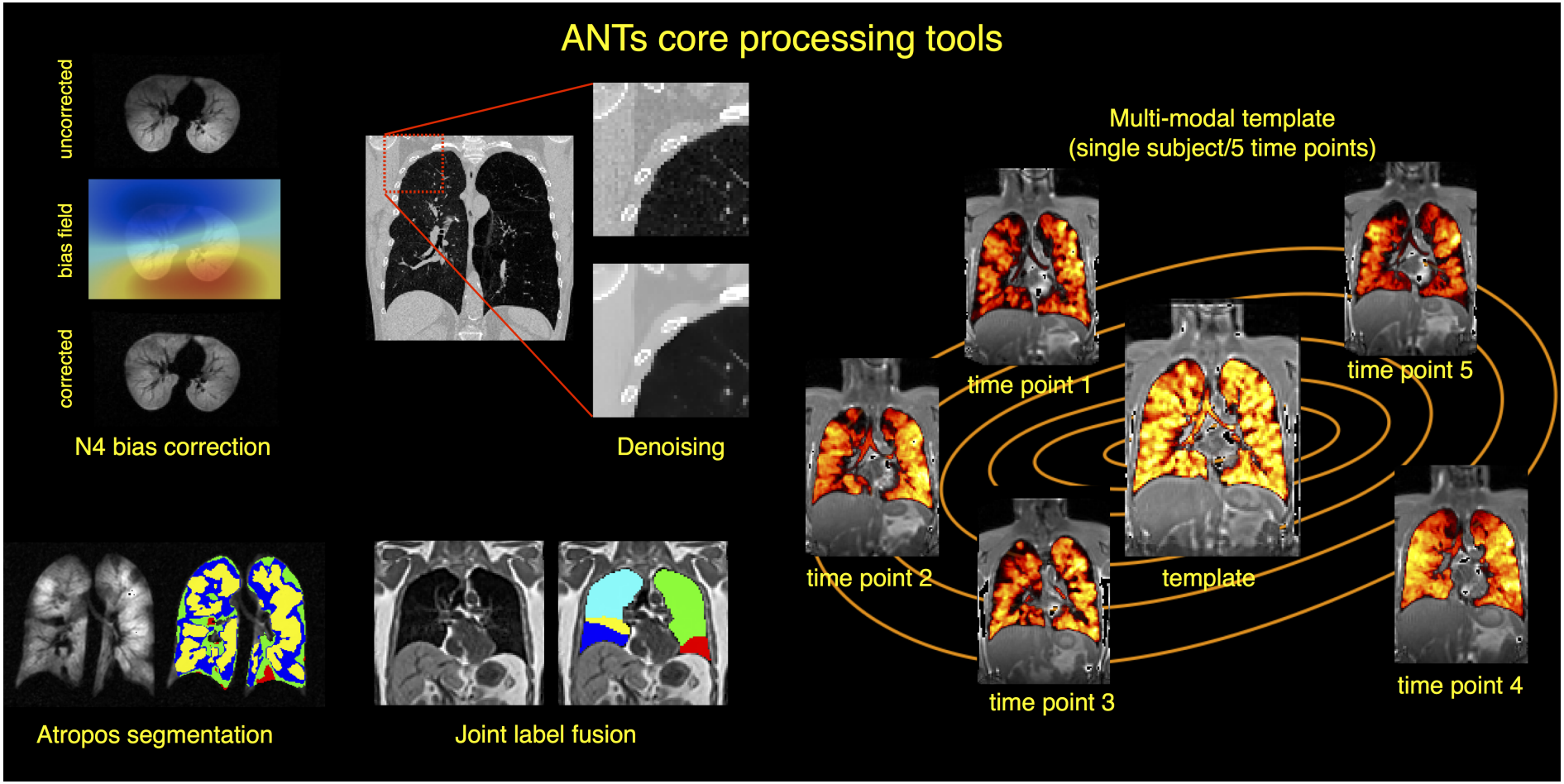
Donoho?

"Papers are just advertisements for the science."

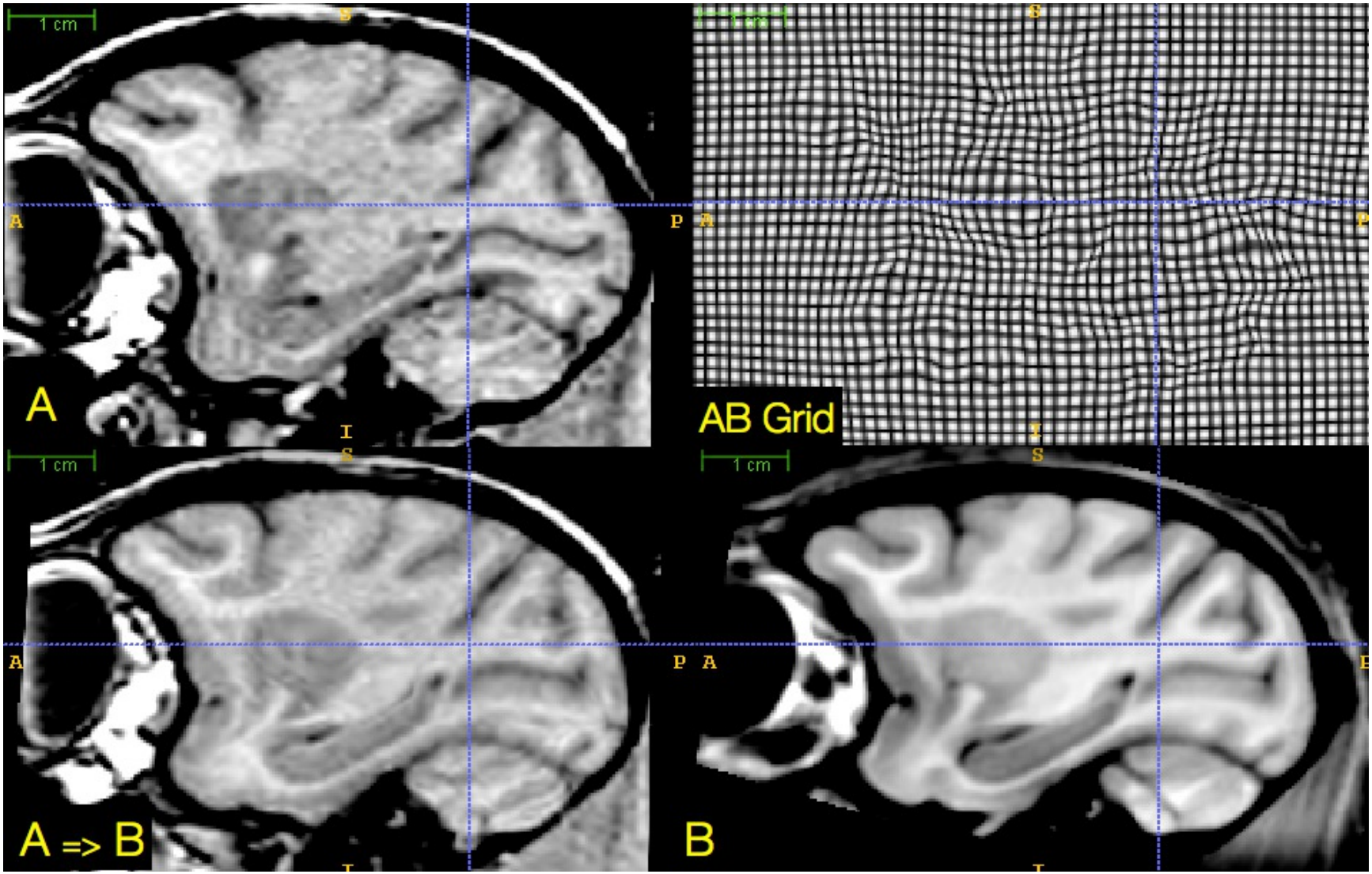
Neuro tools


ANTs core processing tools
IXI 061
N4 bias correction
Denoising
Atropos segmentation
Joint label fusion
IXI multi-modal template (female 50-60)
IXI 157
IXI 536
IXI 259
IXI 400
IXI 312

Pulmonary tools



Diffeomoprhisms: differentiable map with diff. inverse



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[1]*, Nicholas J. Tustison[2], Michael Stauffer[1], Gang Song[1], Baohua Wu[1] and James C. Gee[1]

[1] *Penn Image Computing and Science Laboratory, Department of Radiology, University of Pennsylvania, Philadelphia, PA, USA*
[2] *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

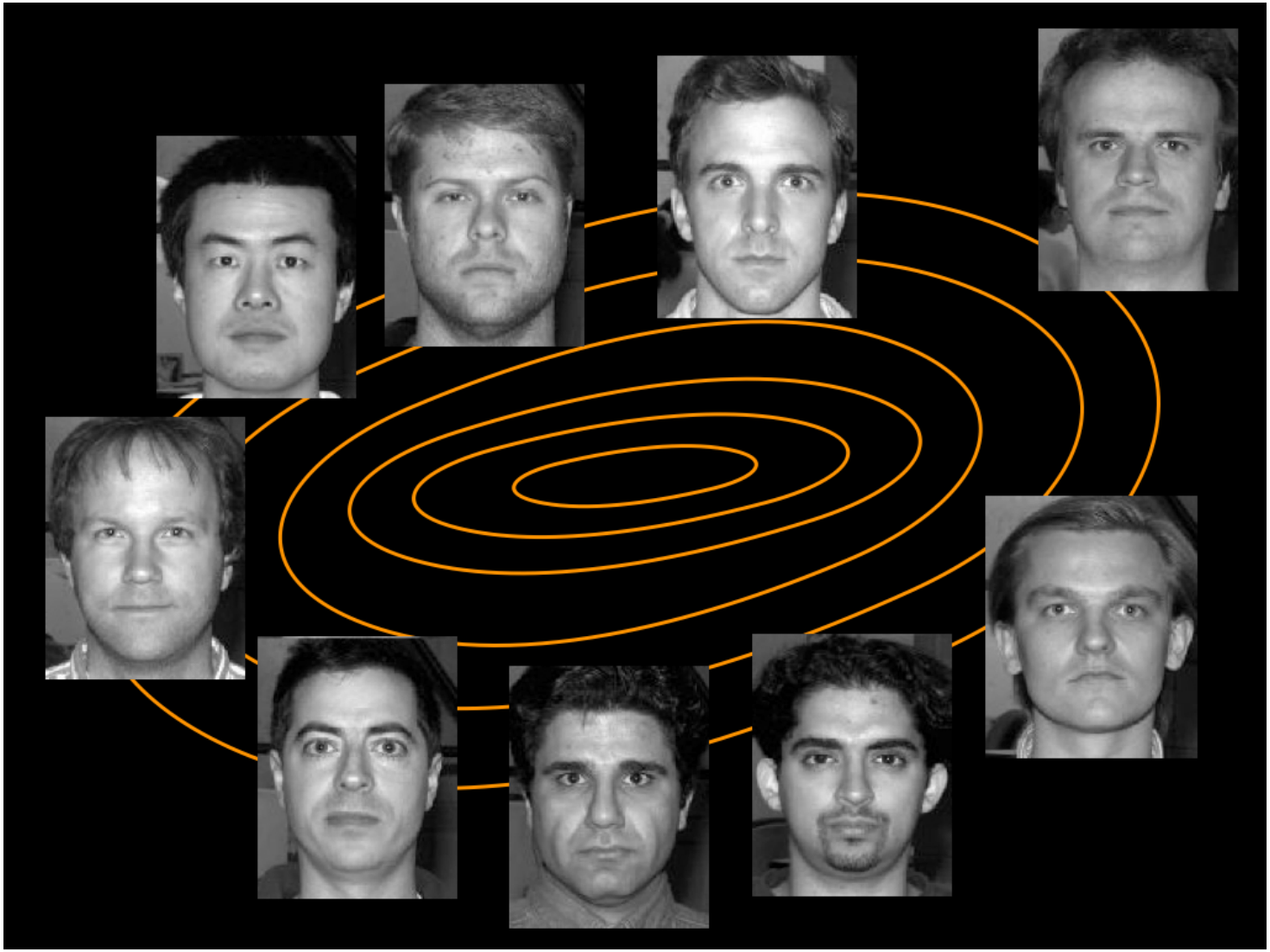
Explicit B-spline regularization in diffeomorphic image registration

Nicholas J. Tustison[1]* and Brian B. Avants[2]

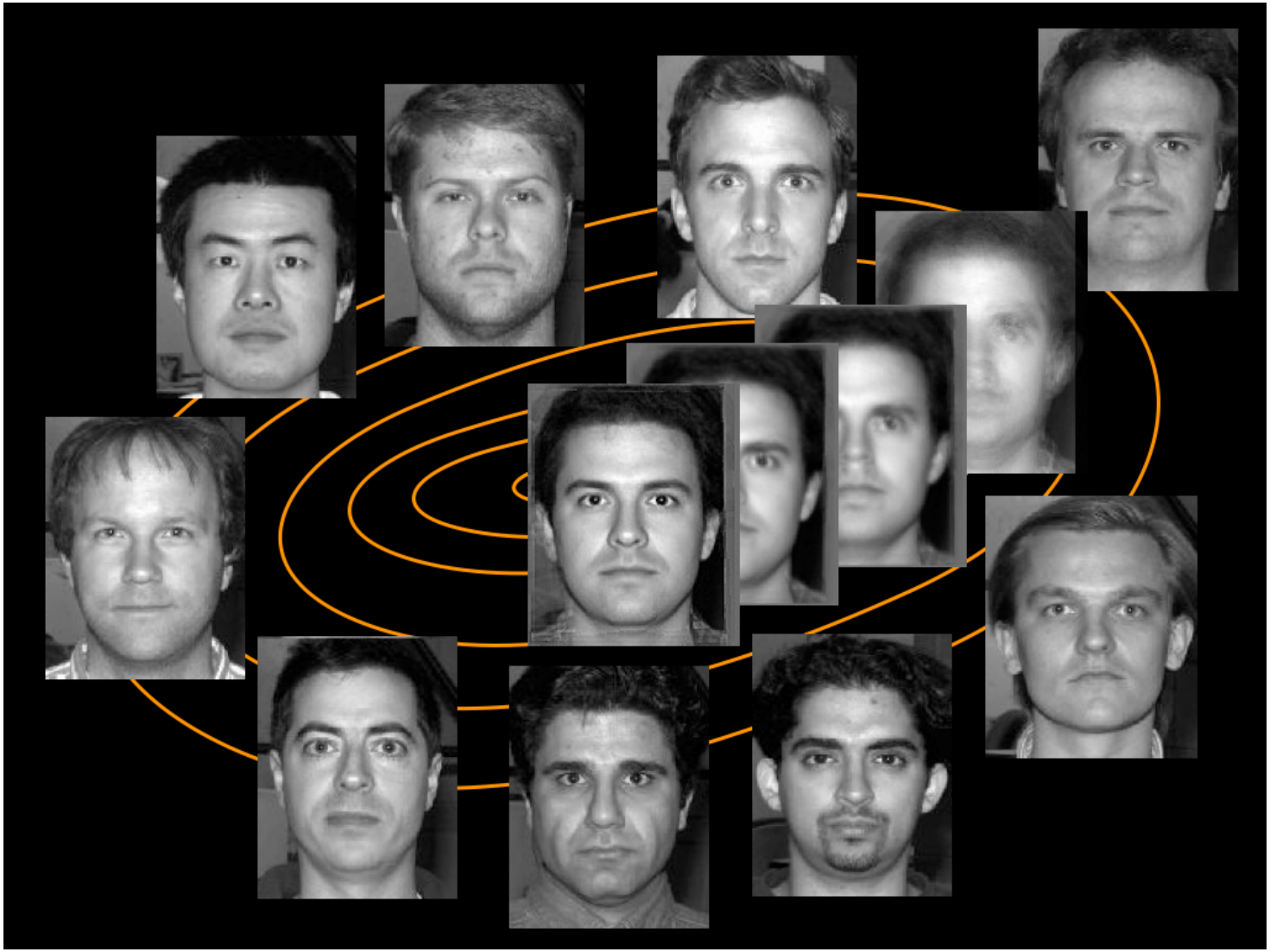
antsRegistration

```
$ antsRegistration --help

COMMAND:
     antsRegistration
          This program is a user-level registration applicatio
          ITKv4-only classes. The user can specify any number
          consists of a transform; an image metric; and iterat
          smoothing sigmas for each level.Note that dimensiona
          output, convergence, shrink-factors and smoothing-si
          mandatory.

OPTIONS:
     --version
          Get Version Information.

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

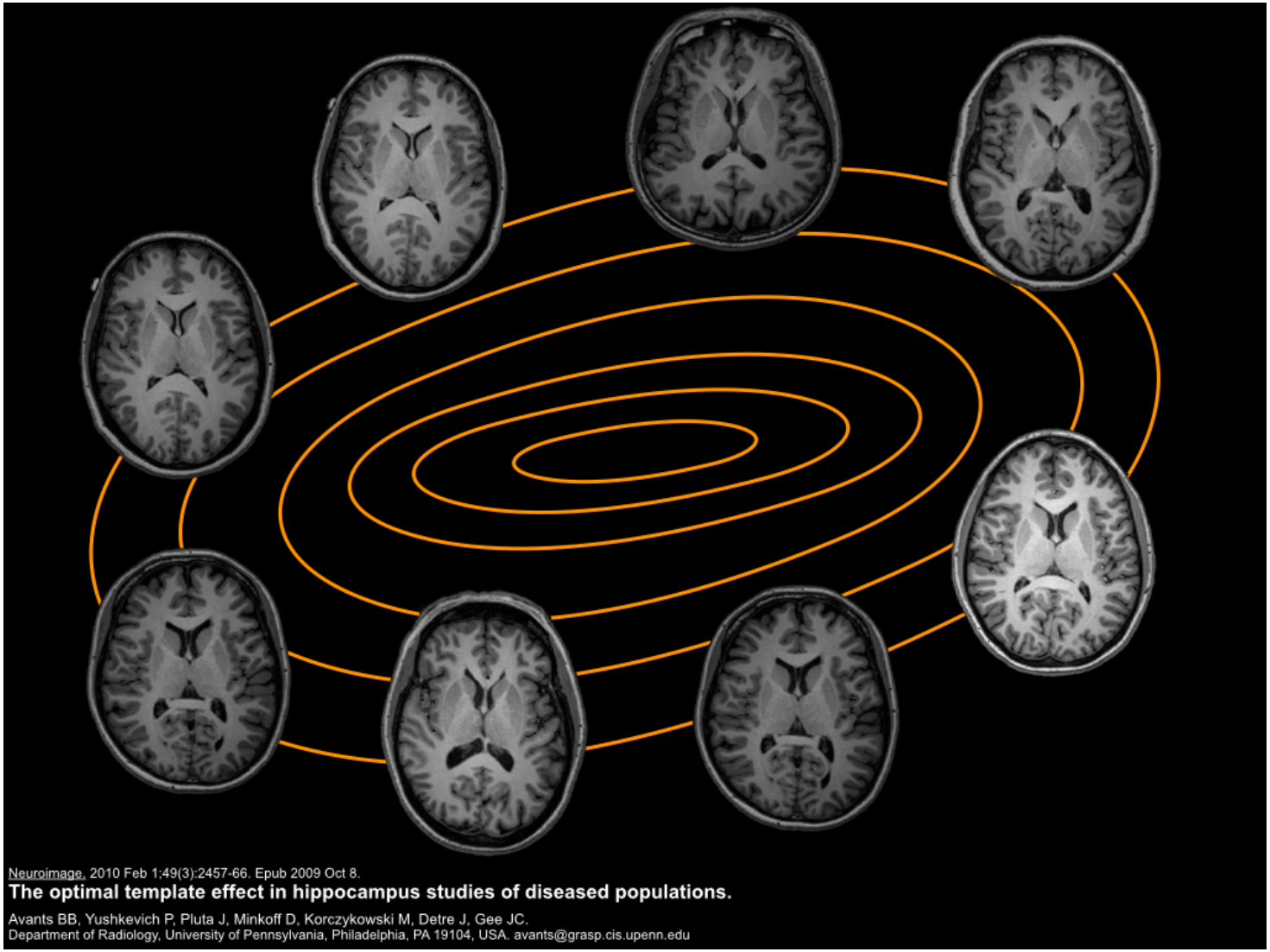
Template building: creating the average Joe



"Attractiveness" $\rightarrow$ mental processing?

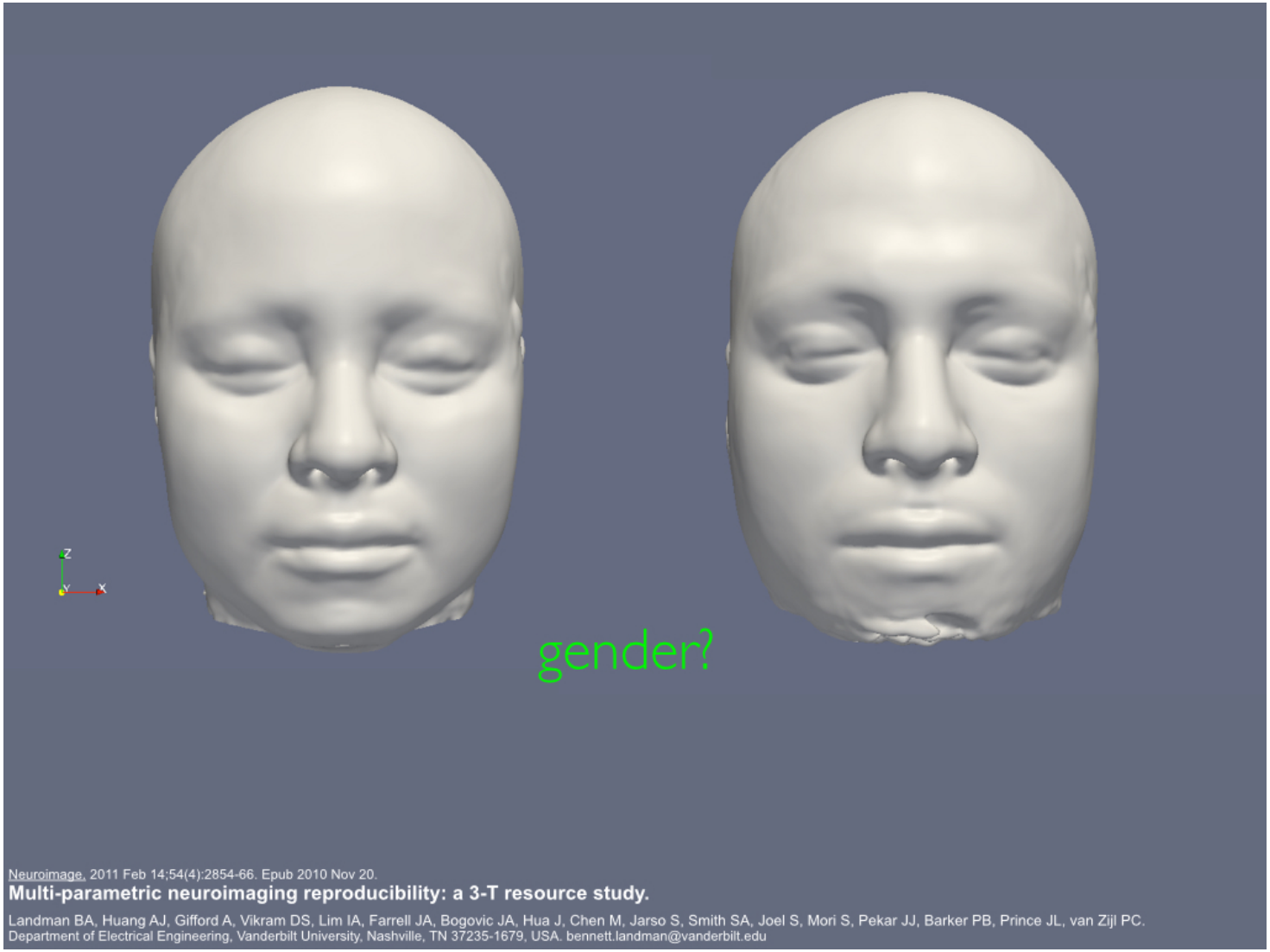


What about brains?



Templates facilitate computation

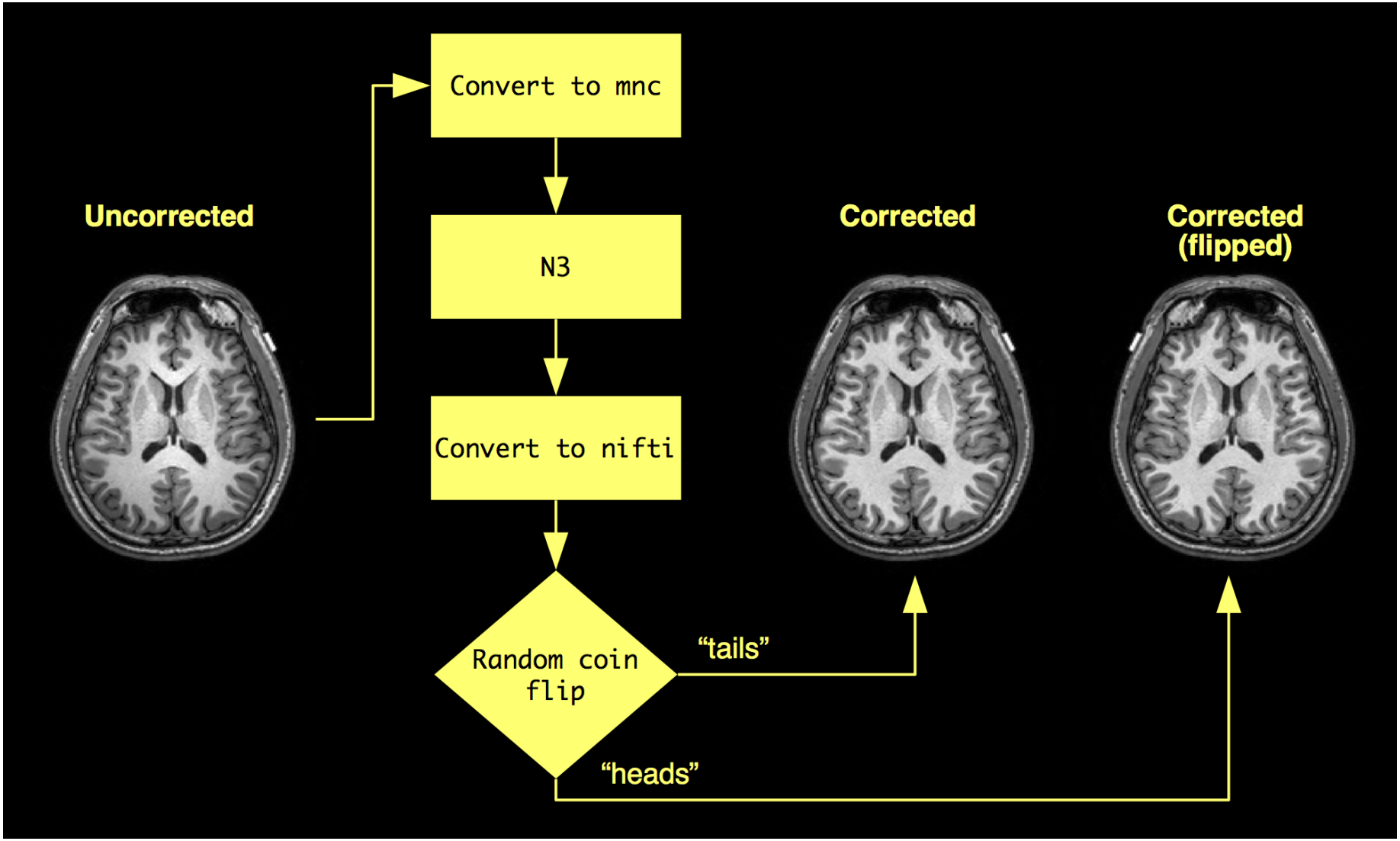
Gender discernibility?



antsMultivariateTemplateConstruction.sh

```
$ antsMultivariateTemplateConstruction.sh

Usage:

antsMultivariateTemplateConstruction.sh -d ImageDimension -o O

Compulsory arguments (minimal command line requires SGE cluste

     -d:  ImageDimension: 2 or 3 (for 2 or 3 dimensional regis
   ImageDimension: 4 (for template generation of time-series d

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

<images>  List of images in the current directory, eg *_t1.nii
          of the command.  Optionally, one can specify a .csv
          line is the location of the input image.  One can al
```

N3 adoption issues

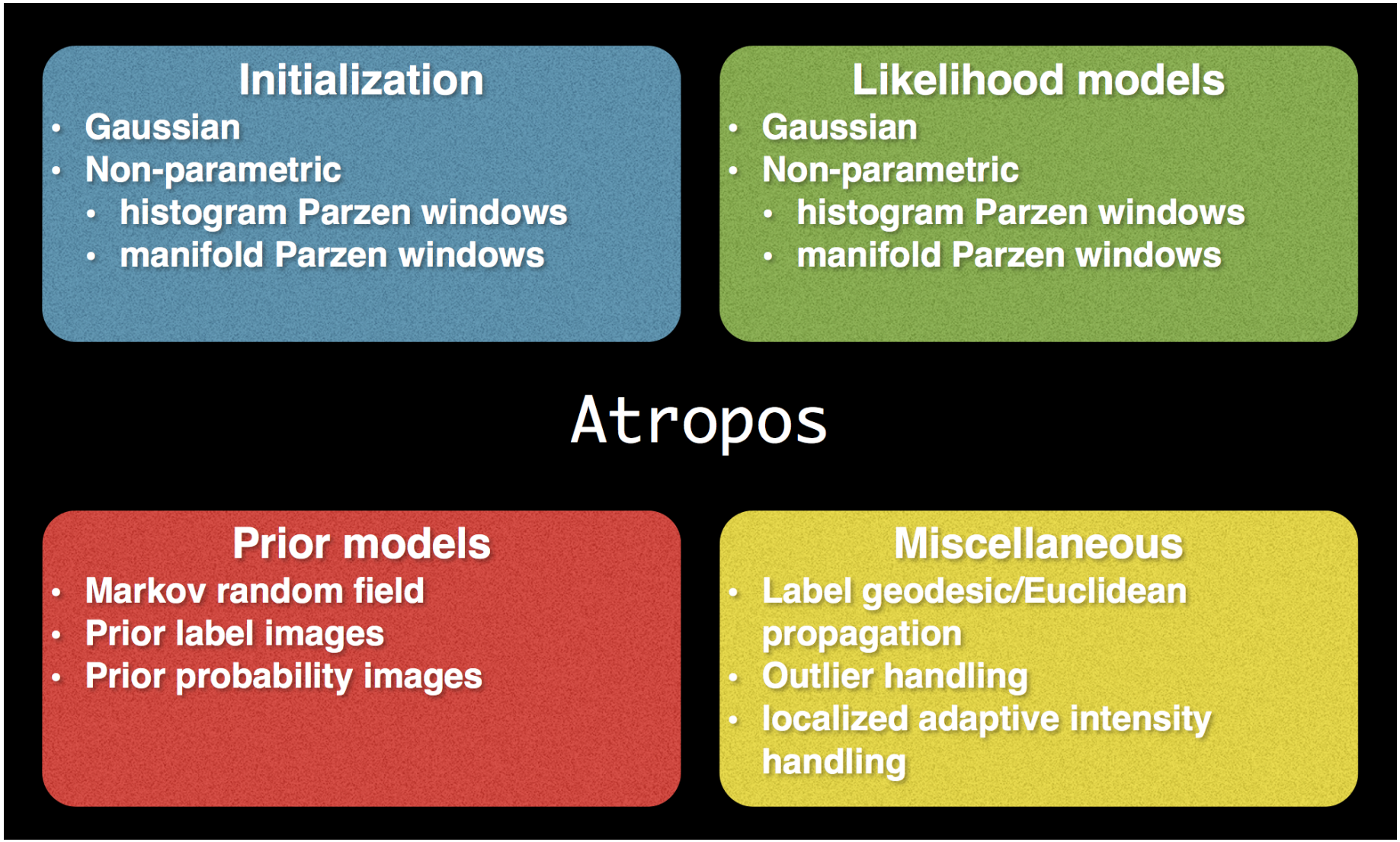


N4BiasFieldCorrection

```
$ N4BiasFieldCorrection --help

COMMAND:
     N4BiasFieldCorrection
          N4 is a variant of the popular N3 (nonparameteric no
          retrospective bias correction algorithm. Based on th
          corruption of the low frequency bias field can be mo
          the intensity histogram by a Gaussian, the basic alg
          iterate between deconvolving the intensity histogram
          the intensities, and then spatially smoothing this r
          of the bias field itself. The modifications from and
          the original N3 algorithm are described in the follo
          al., N4ITK: Improved N3 Bias Correction, IEEE Transa
          29(6):1310-1320, June 2010.

OPTIONS:
```

Atropos: flexible code base

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



Atropos

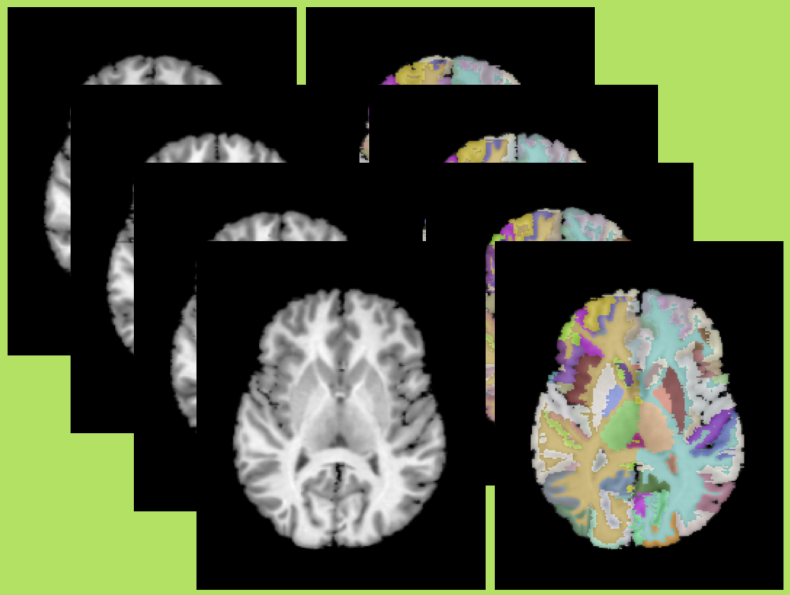
```
$ Atropos --help

COMMAND:
     Atropos
          A finite mixture modeling (FMM) segmentation approac
          specifying prior constraints. These prior constraint
          of a prior label image, prior probability images (or
          MRF prior to enforce spatial smoothing of the labels
          FAST and SPM. Reference: Avants BB, Tustison NJ, Wu
          source multivariate framework for n-tissue segmentat
          public data. Neuroinformatics. 2011 Dec;9(4):381-400

OPTIONS:
     -d, --image-dimensionality 2/3/4
          This option forces the image to be treated as a spec
          not specified, Atropos tries to infer the dimension
```

DenoiseImage — contribution from Jose Manjon

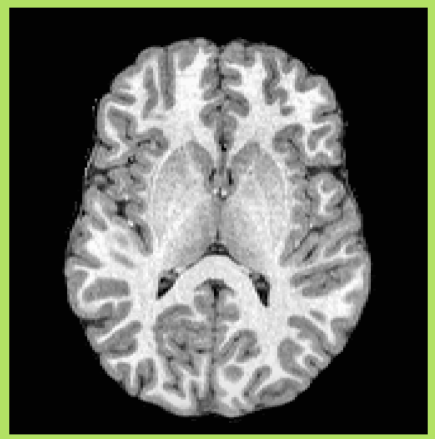
```
$ DenoiseImage --help


COMMAND:
     DenoiseImage
          Denoise an image using a spatially adaptive filter o
          Manjon, P. Coupe, Luis Marti-Bonmati, D. L. Collins,
          Non-Local Means Denoising of MR Images With Spatiall
          Journal of Magnetic Resonance Imaging, 31:192-203, J

OPTIONS:
     -d, --image-dimensionality 2/3/4
          This option forces the image to be treated as a spec
          not specified, the program tries to infer the dimens
          image.
```

Multi-atlas segmentation

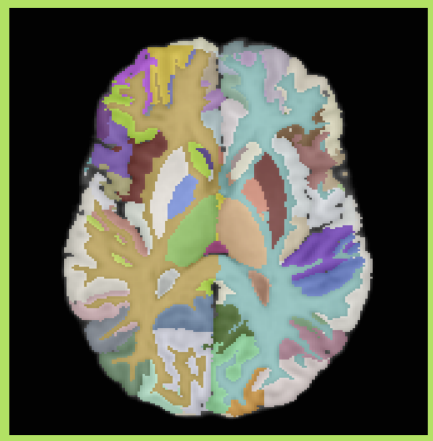
Joint label fusion



Atlases
(grayscale + segmentation)



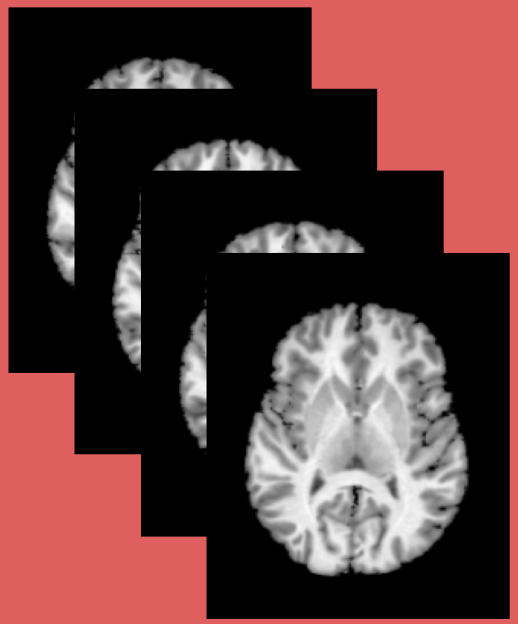
Target image



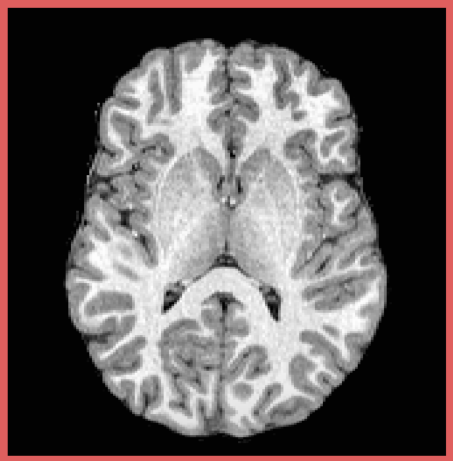
Target segmentation

New work: joint intensity fusion

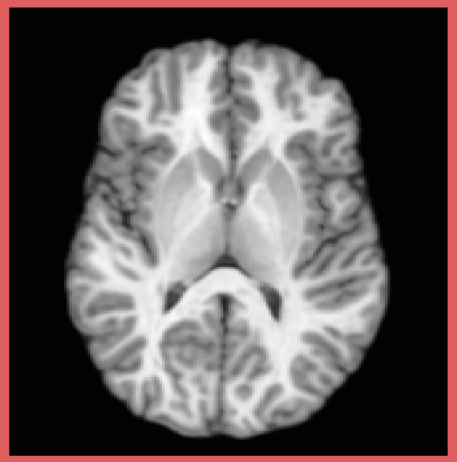
Joint intensity fusion



Atlases
(grayscale only)



Target image



Target fusion image

Possible uses

- "Correct" images
  - motion correction
  - "remove" lesions
- Project atlas set intensity signature
- Use in "corrective learning"

antsJointFusion — contribution from Hongzhi Wang (with some added features)

```
$ antsJointFusion --help

COMMAND:
     antsJointFusion
          antsJointFusion is an image fusion algorithm develop
          Yushkevich which won segmentation challenges at MICC
          original label fusion framework was extended to acc
          Avants. This implementation is based on Paul's origi
          and Brian's ANTsR implementation. References include
          Das, J. Pluta, C. Craige, P. Yushkevich, Multi-atlas
          label fusion IEEE Trans. on Pattern Analysis and Mac
          611-623, 2013. and 2) H. Wang and P. A. Yushkevich,
          with joint label fusion and corrective learning--an
          Front. Neuroinform., 2013.
```

Putting it all together—the ANTs cortical thickness pipeline

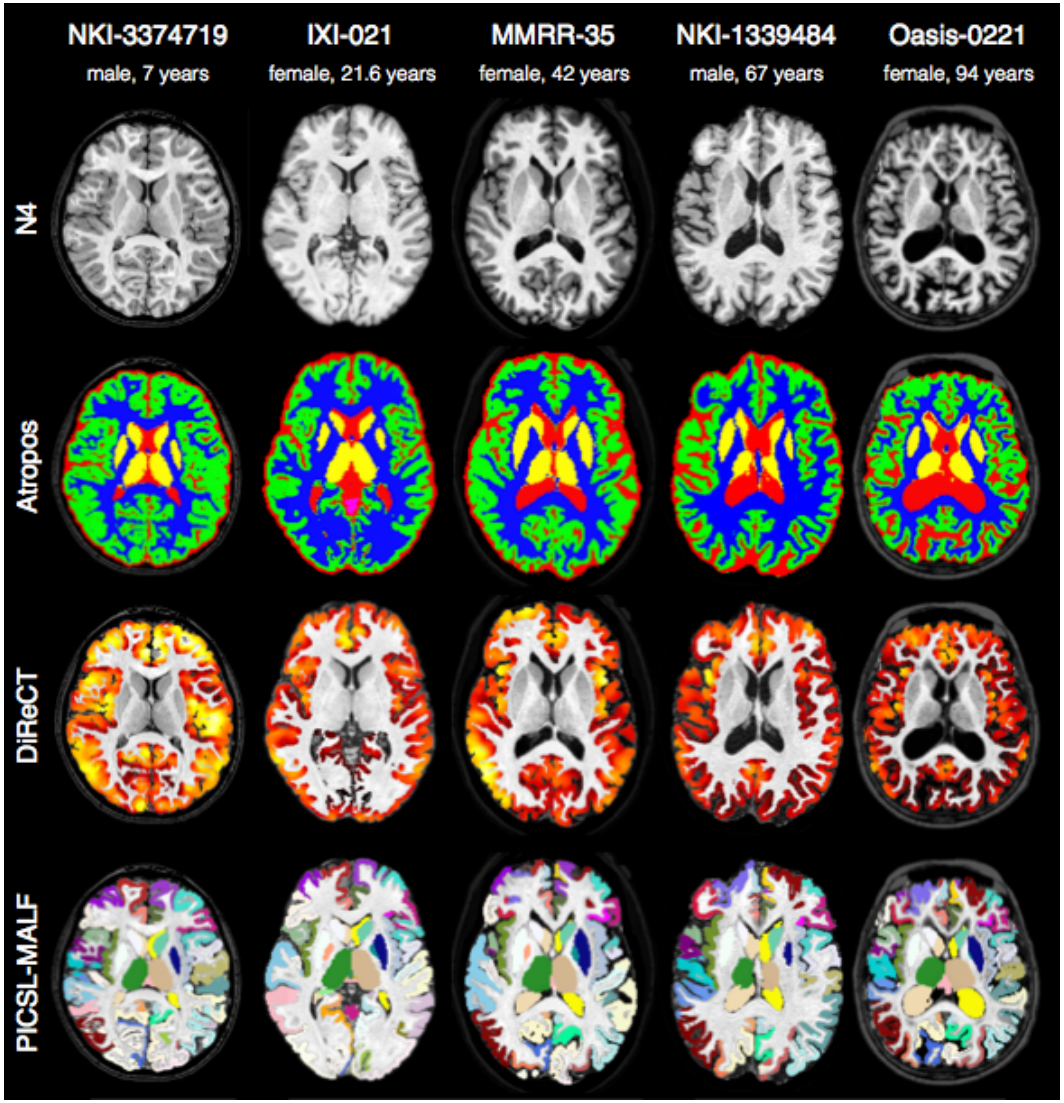
Cortical thickness studies

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
migraines	athletic ability
chronic smoking	meditative practices
alcoholism	musical ability
cocaine addiction	tendency toward criminality

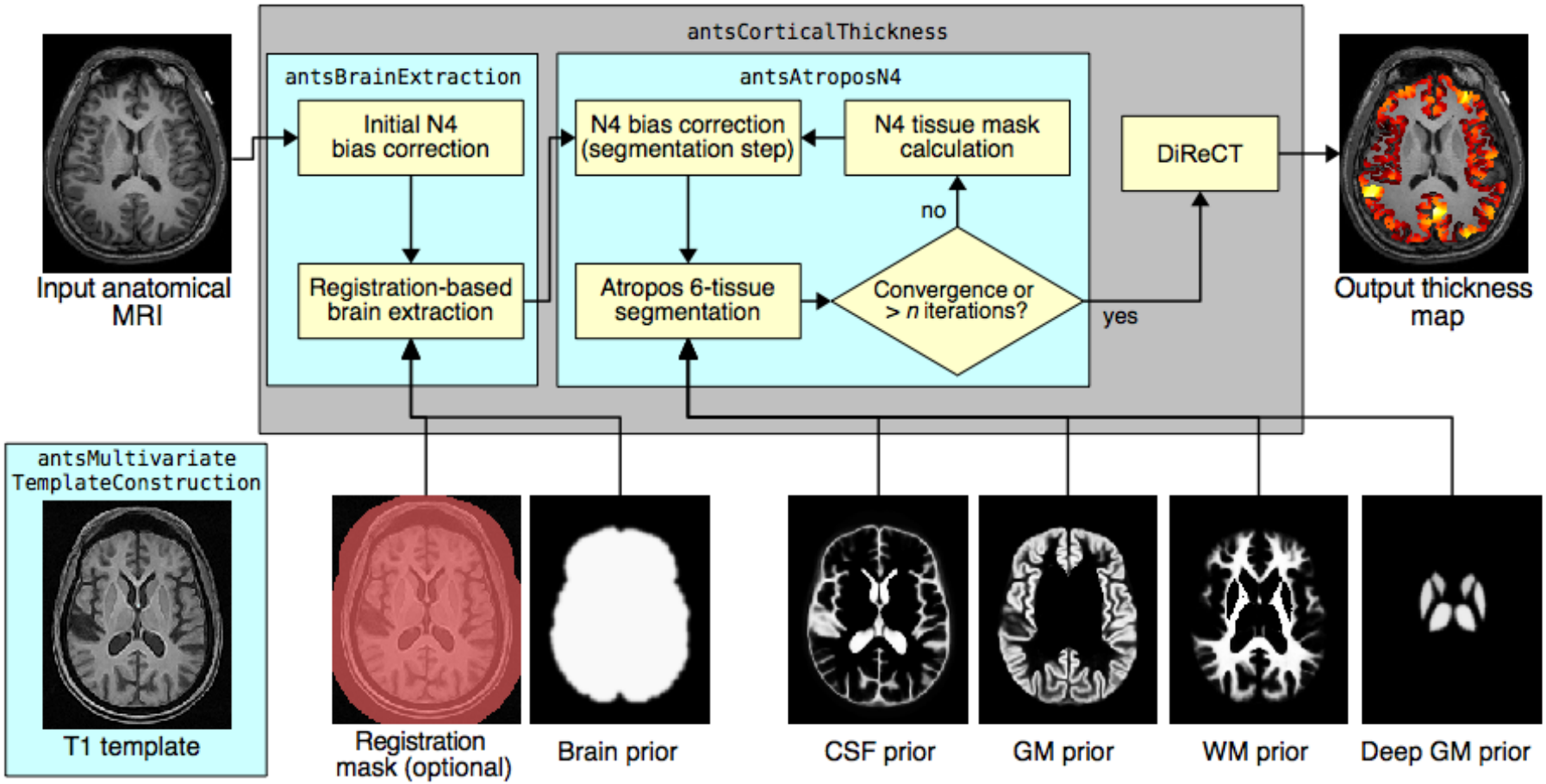
Basic components of the pipeline

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

Sample results

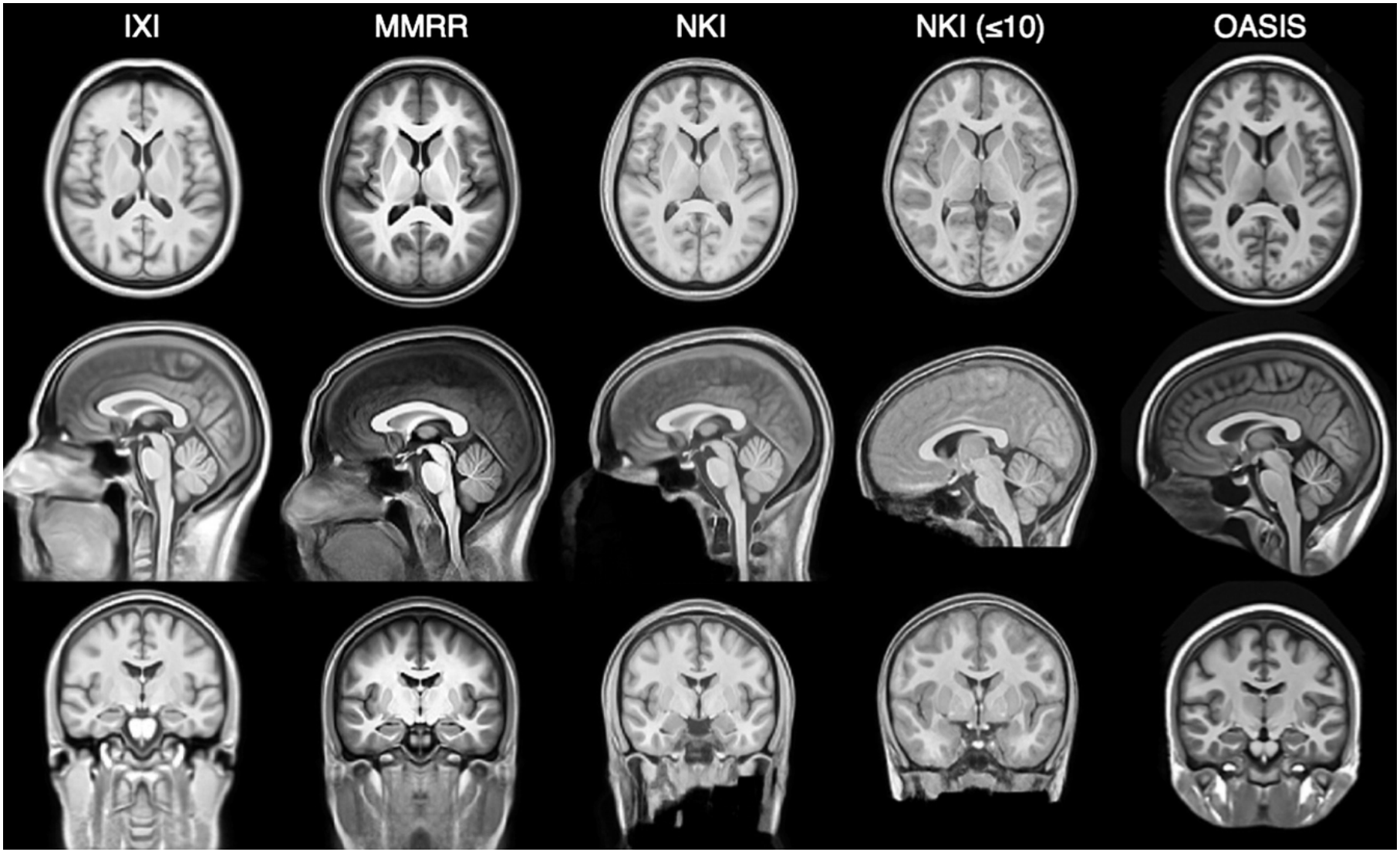


The ANTs structural brain mapping workflow

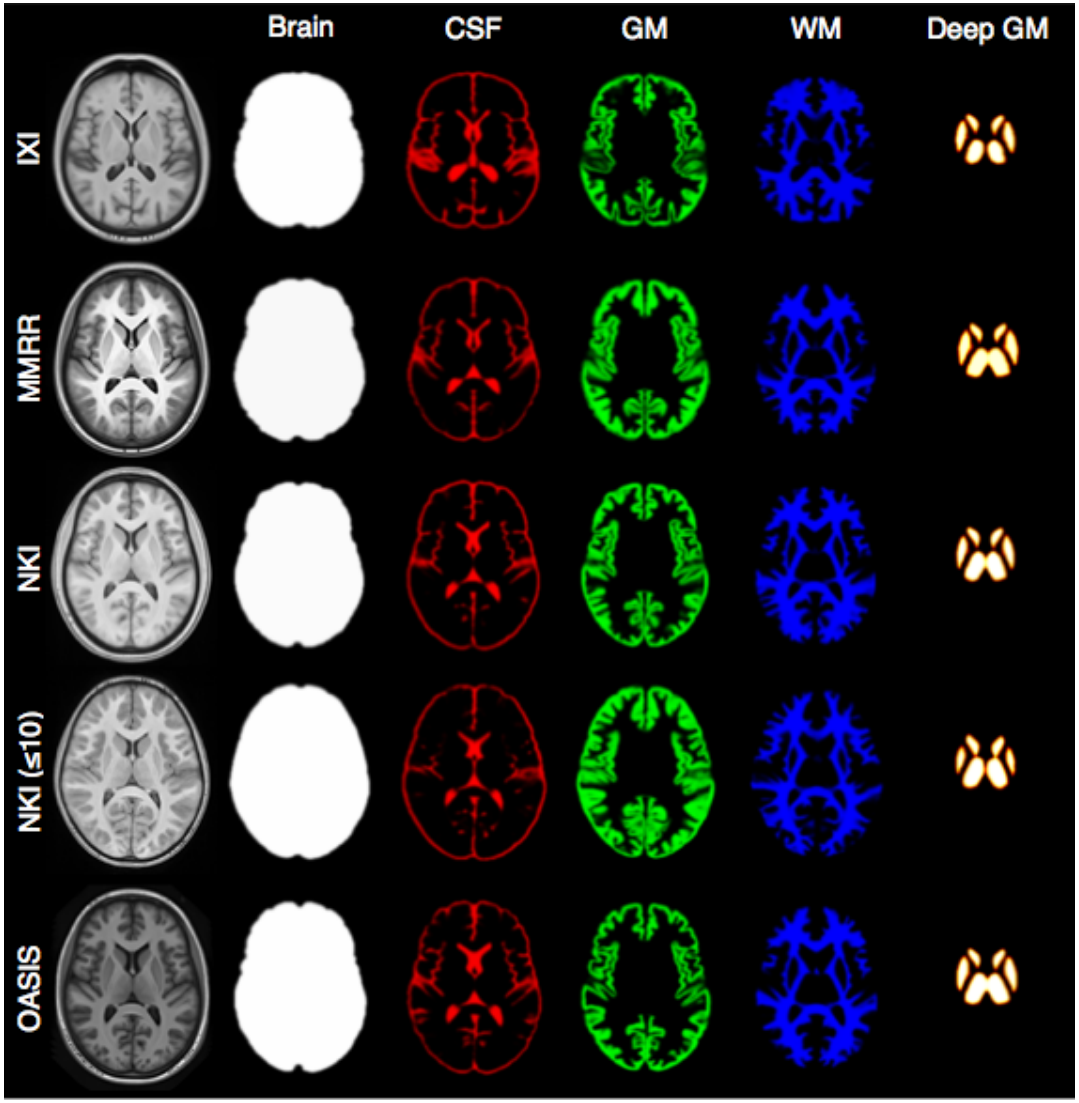


Template building

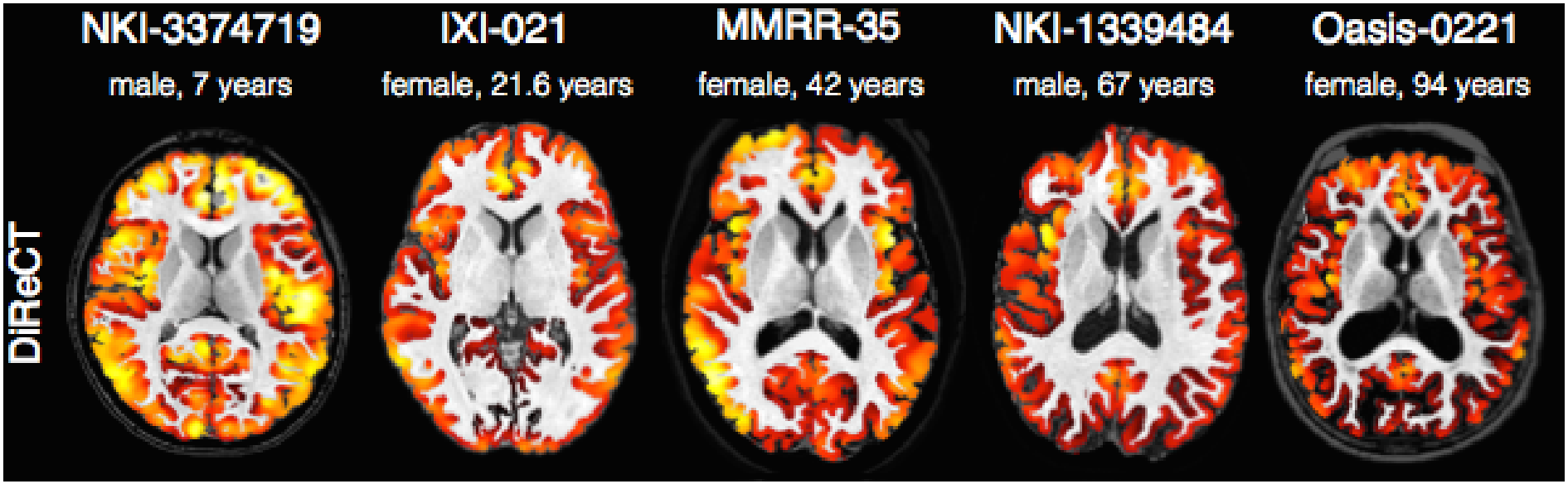
Tailor data to your specific cohort



Template priors



Cortical thickness maps



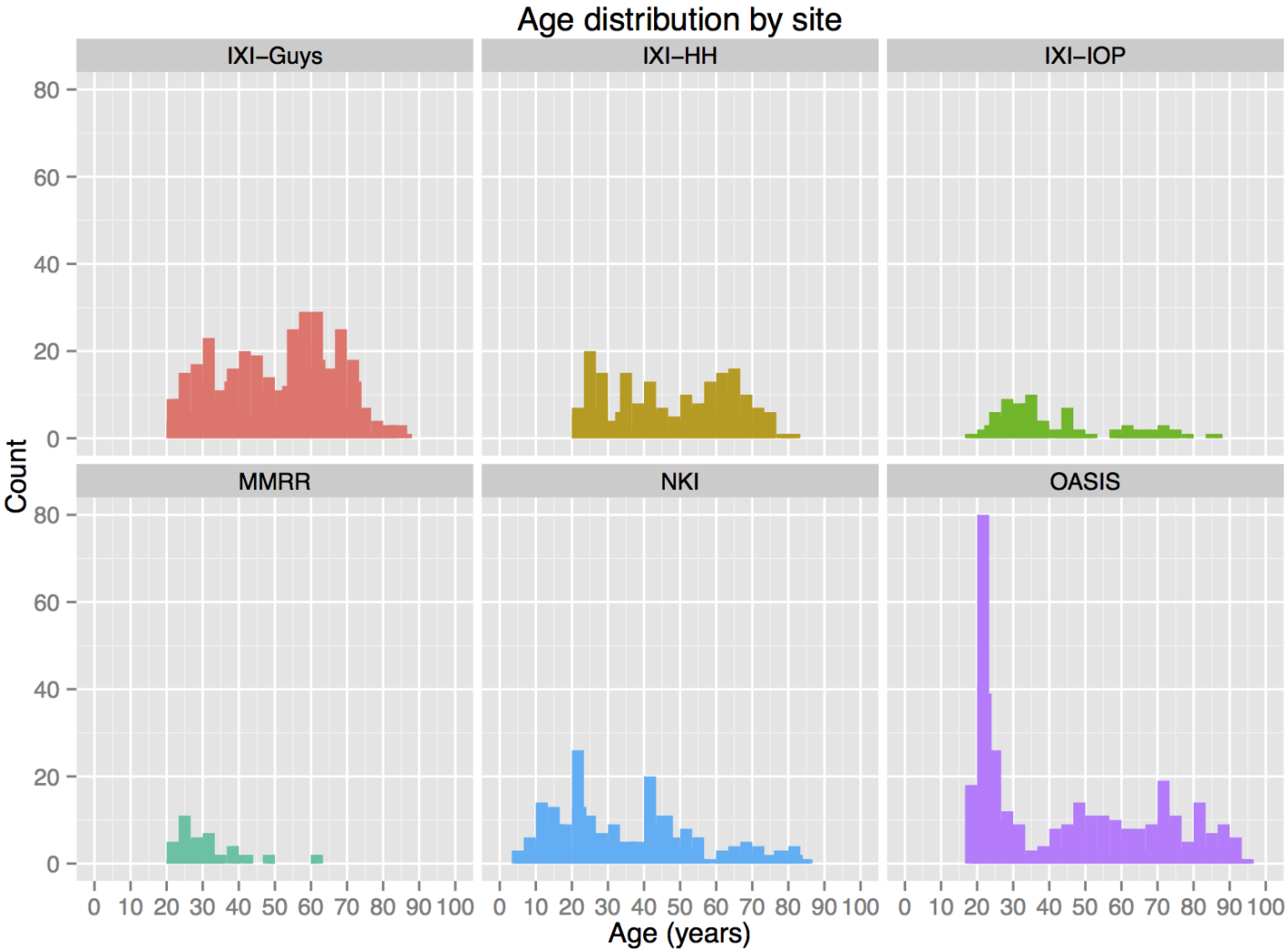
In contrast to FreeSurfer which warps coupled surface meshes to segment the gray matter, *ANTs* diffeomorphically registers the white matter to the combined gray/white matters while simultaneously estimating thickness.

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

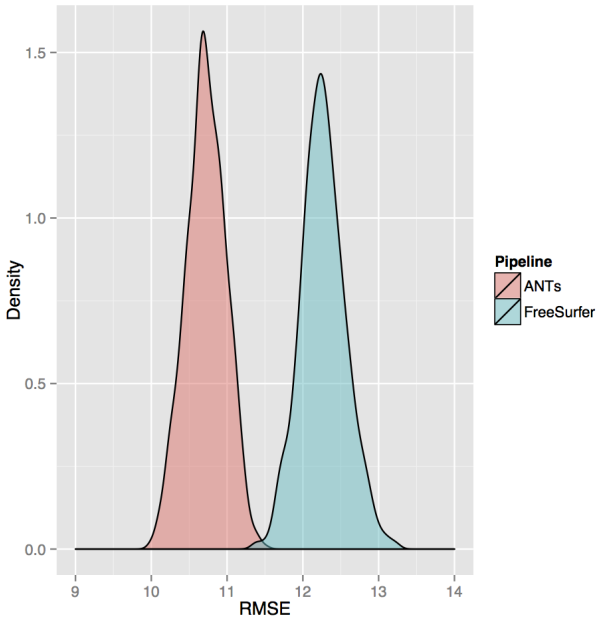
Predict age and gender

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

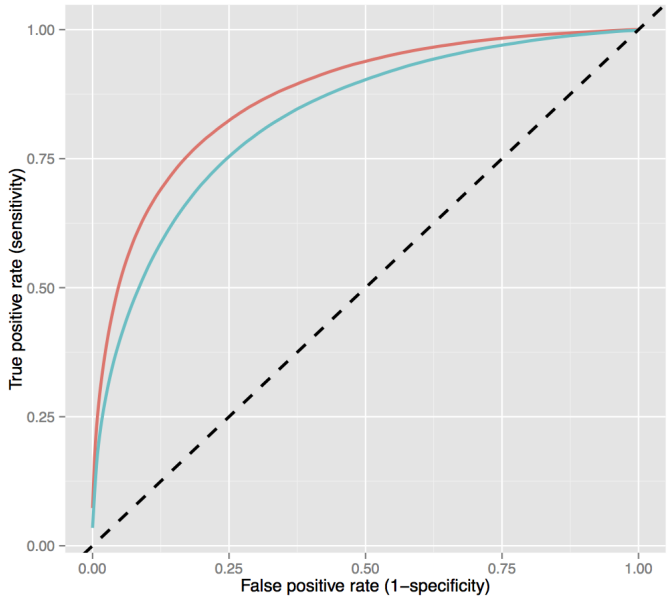
Open science principles

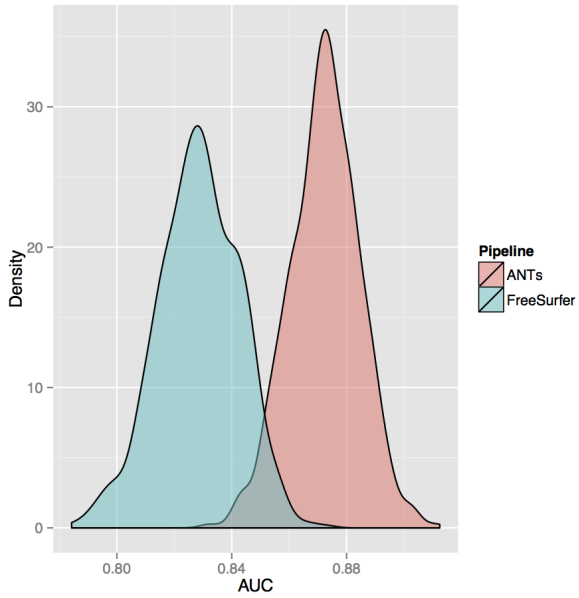


Prediction from cortical thickness data



Age





Gender

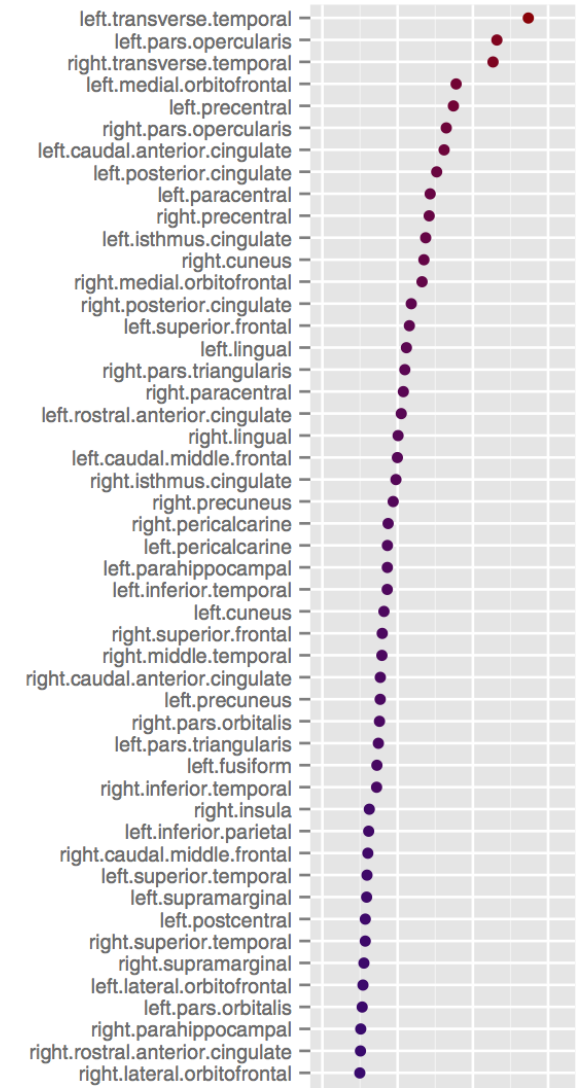
Age prediction per site

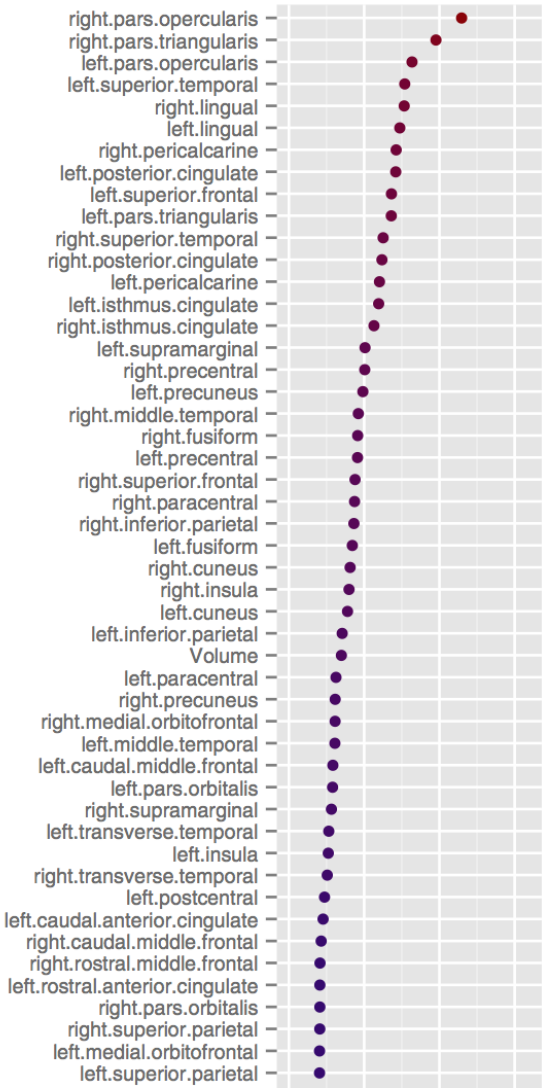
Table 3
Mean RMSE for age prediction in years.

	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[a]	10.9
FreeSurfer (NKI)	NA[a]	13.3
ANTs (OASIS)	15.0	12.4
FreeSurfer (OASIS)	15.0	11.4

[a] Fitting error.

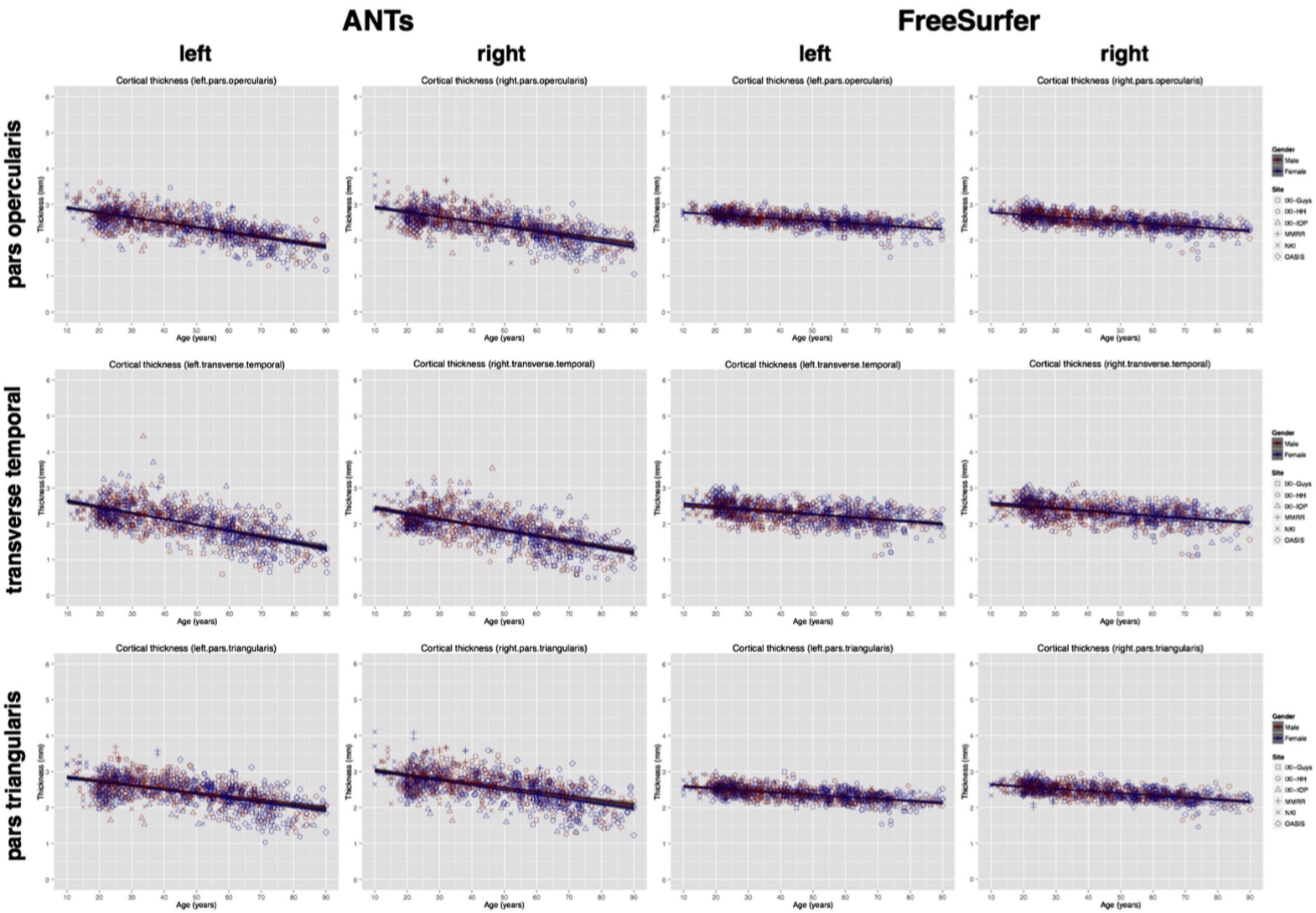
Regional importance comparison





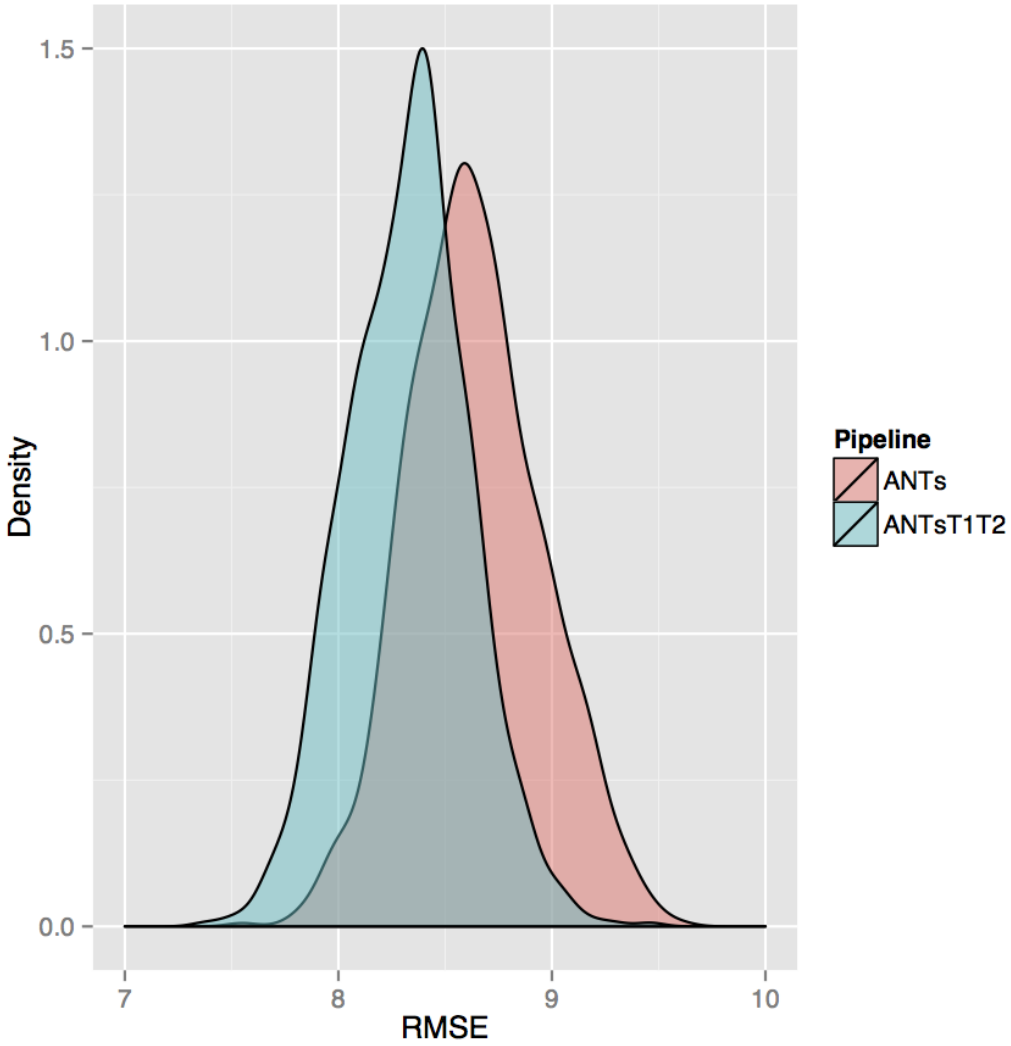
ANTs (left) vs. FreeSurfer (right)

Regional measurements



But, wait, there's more!

ANTs tools are multivariate

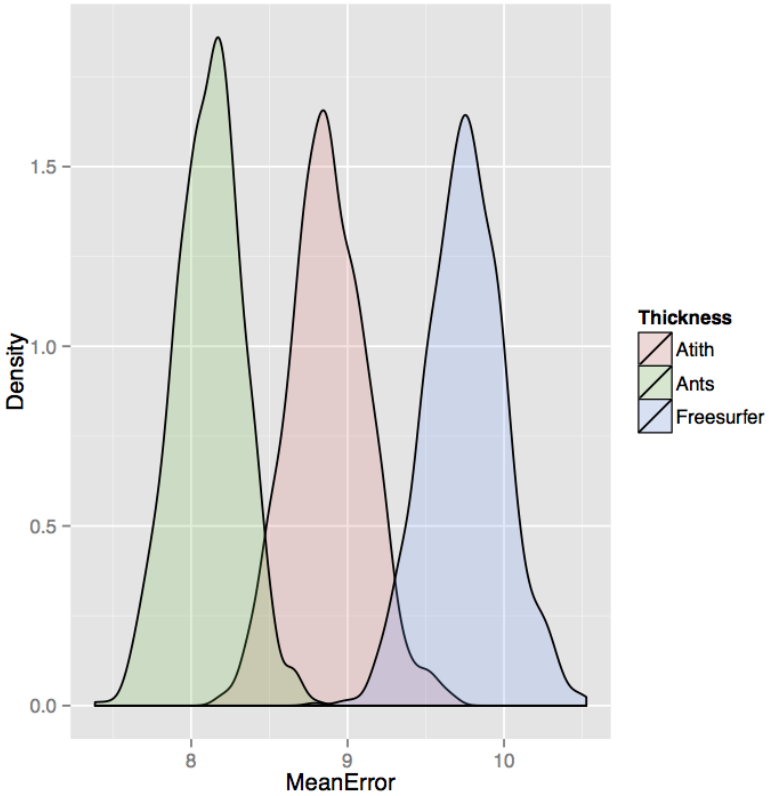


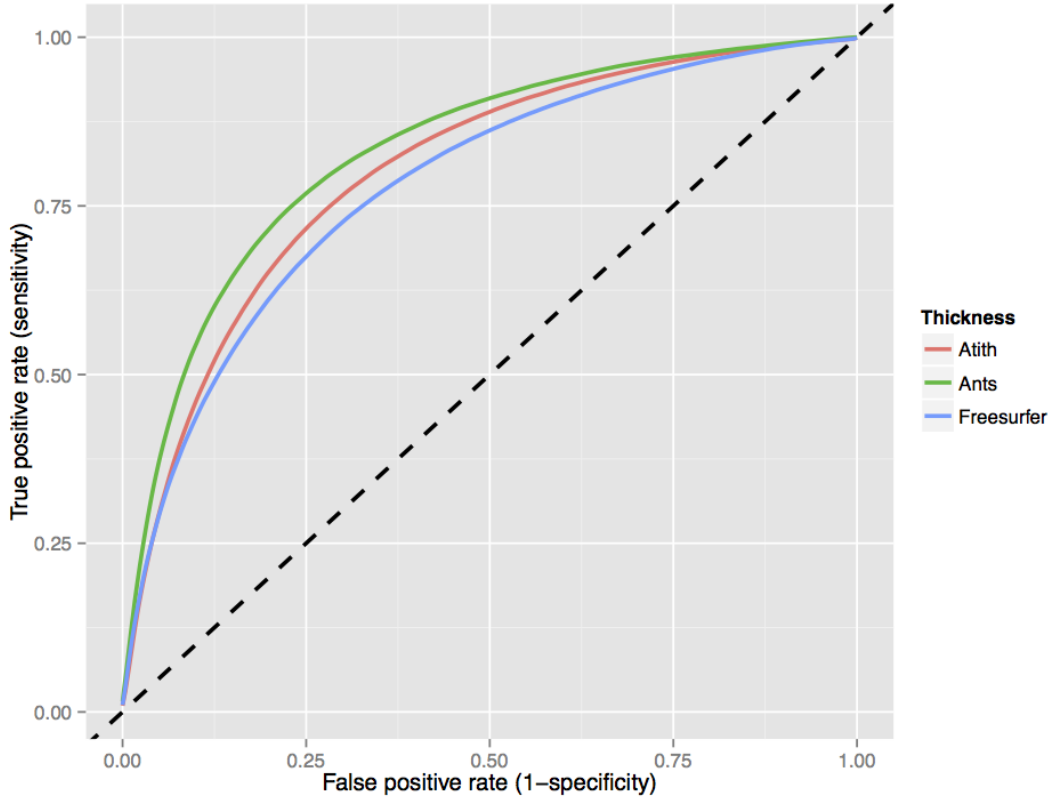
Arno-thick-in-the-head (ATITH)

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

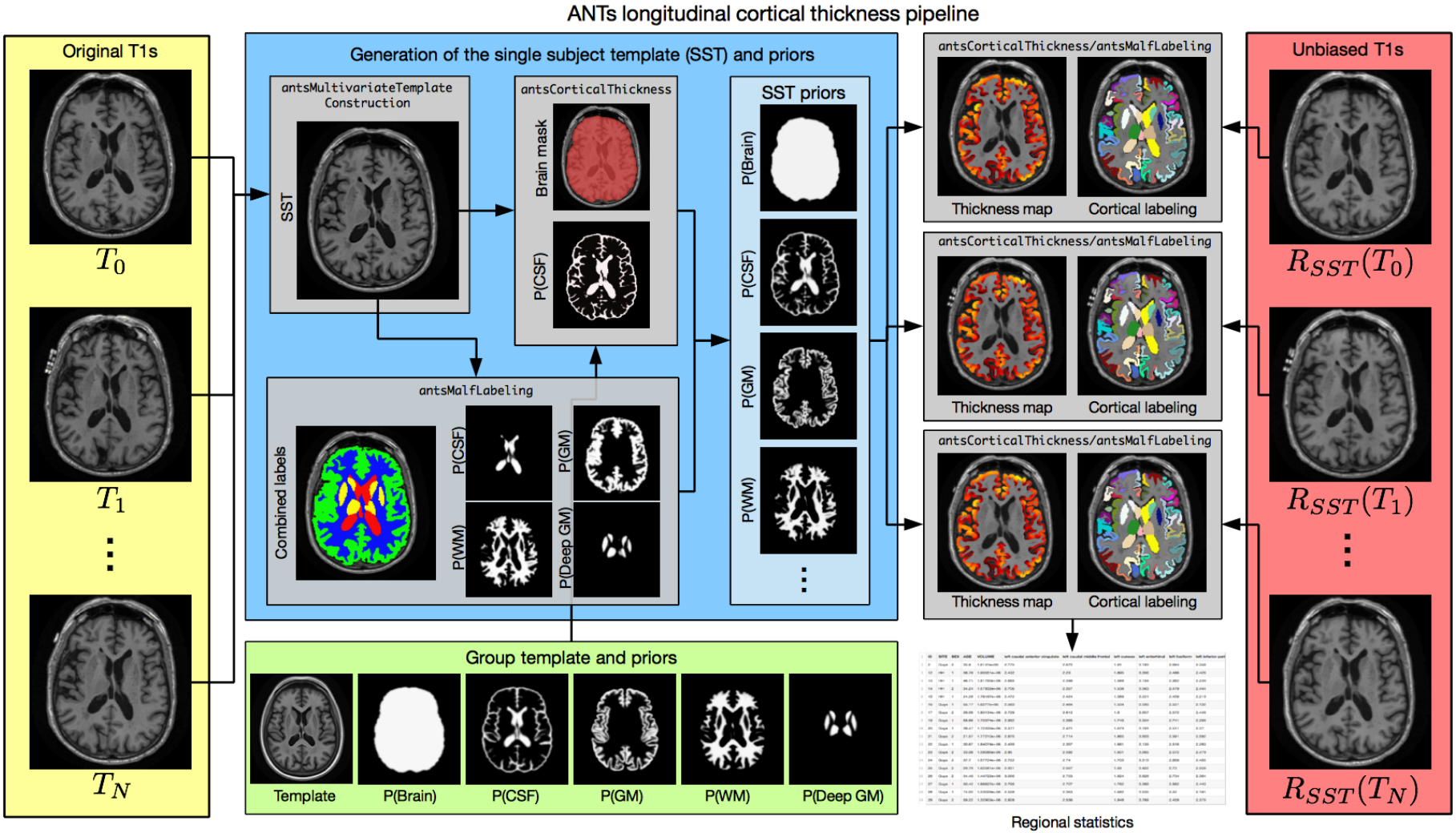
$$thickness_{ROI} = \frac{volume_{ROI}}{area_{ROI}}$$

Prediction from cortical thickness data





Longitudinal processing



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-
```

Data availability

- "*Hey, can I have the FreeSurfer measurements for the entorhinal cortex?*" Sure, why not?—Hasan, et al., J Neuroimaging
- "*Can I have one or more of the templates that you used for your study?*" Would you like the priors as well?

Current work and Advanced Normalization Tools in R (ANTsR)

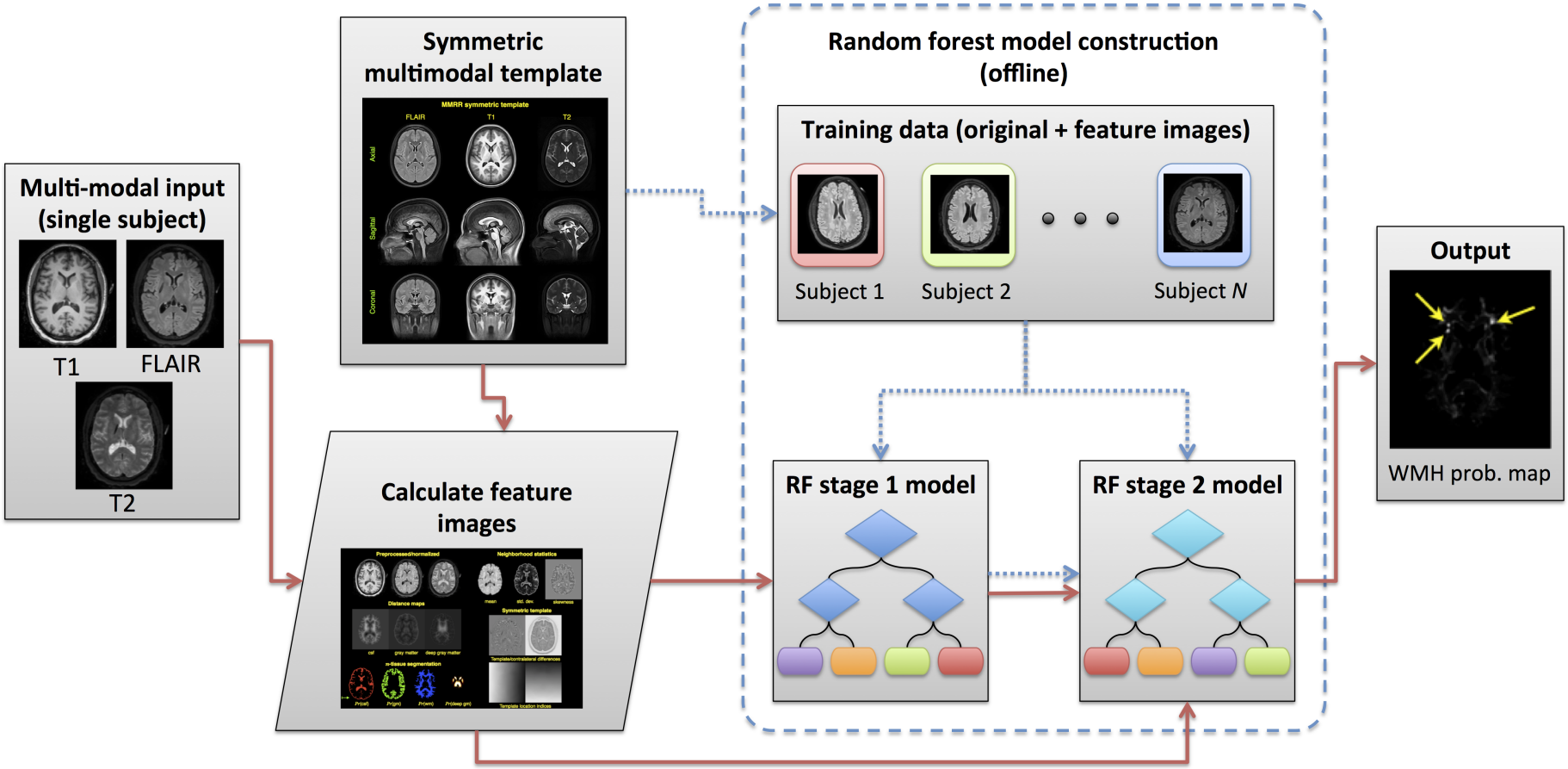
Multimodal Brain Tumor Segmentation (BRATS 2013)

Patient

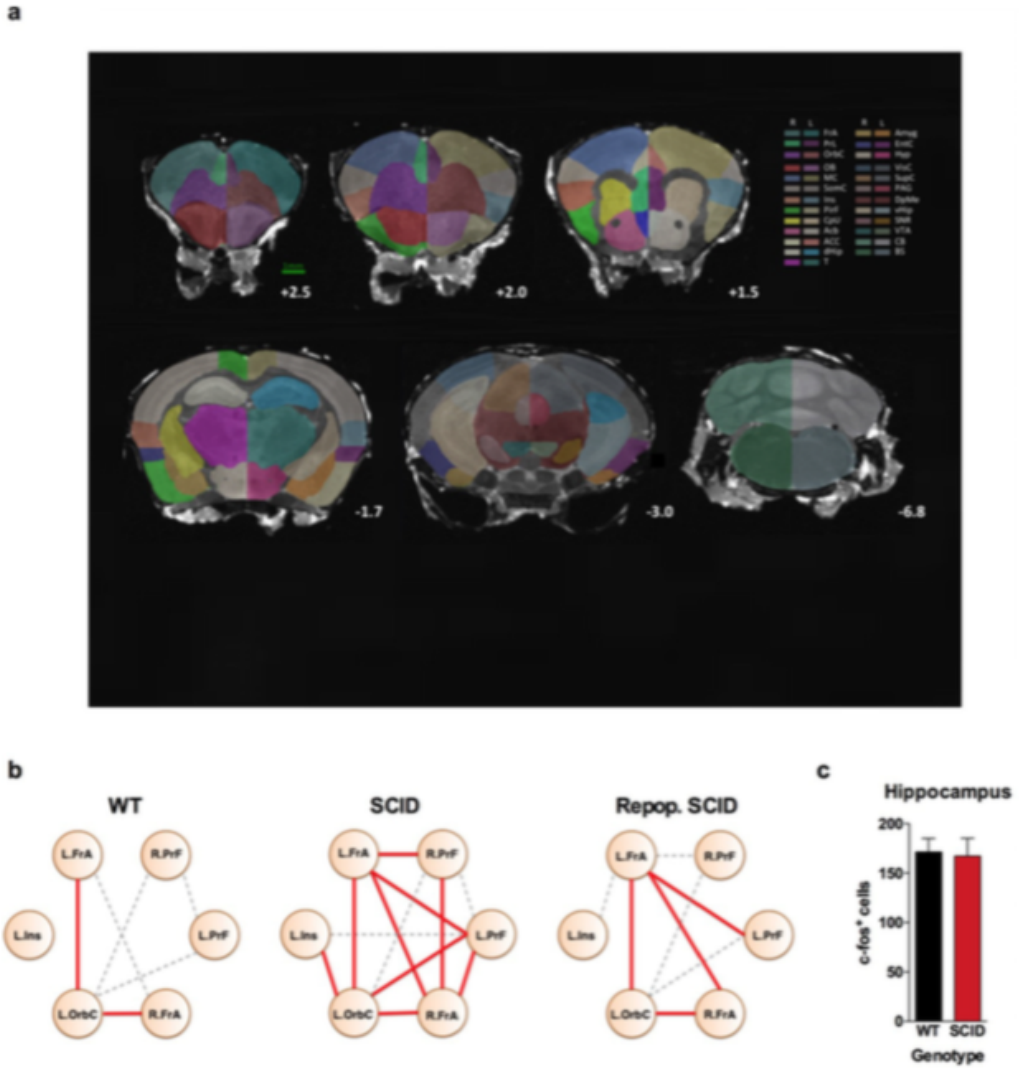
Position	User	Dice			Positive Predictive Value			Sensitivity			Kappa	Complete tumor Rank	Tumor core Rank	Enhancing tumor Rank
		complete	core	enhancing	complete	core	enhancing	complete	core	enhancing				
1	Nick Tustison	0.87 (1)	0.78 (1)	0.74 (1)	0.85 (2)	0.74 (4)	0.69 (4)	0.89 (2)	0.88 (1)	0.83 (1)	0.99 (1)	1.67	2.00	1.89
2	Raphael Meier	0.82 (5)	0.73 (2)	0.69 (3)	0.76 (6)	0.78 (2)	0.71 (1)	0.92 (1)	0.72 (4)	0.73 (3)	0.99 (4)	4.00	2.67	3.00
3	Syed Reza	0.83 (4)	0.72 (3)	0.72 (2)	0.82 (3)	0.81 (1)	0.70 (3)	0.86 (5)	0.69 (6)	0.76 (2)	0.99 (3)	4.00	3.33	3.22
4	Liang Zhao	0.84 (3)	0.70 (4)	0.65 (5)	0.80 (4)	0.67 (5)	0.65 (6)	0.89 (3)	0.79 (3)	0.70 (4)	0.99 (5)	3.33	4.00	4.11
5	Nicolas Cordier	0.84 (2)	0.68 (5)	0.65 (6)	0.88 (1)	0.63 (6)	0.68 (5)	0.81 (6)	0.82 (2)	0.66 (6)	0.99 (2)	3.00	4.33	4.33
6	Joana Festa	0.72 (6)	0.66 (6)	0.67 (4)	0.77 (5)	0.77 (3)	0.70 (2)	0.72 (7)	0.60 (7)	0.70 (5)	0.98 (6)	6.00	5.33	5.00
7	Senan Doyle	0.71 (7)	0.46 (7)	0.52 (7)	0.66 (7)	0.38 (7)	0.58 (7)	0.87 (4)	0.70 (5)	0.55 (7)	0.98 (7)	6.00	6.33	6.44

Tustison, et al., Optimal symmetric multimodal templates and concatenated random forests for supervised brain tumor segmentation (simplified) with *ANTsR*, *Neuroinformatics*.

White matter hyperintensities in TBI



Social behavior and immunity dysfunction in mice



Other ANTsR work

- Pediatric template of brain perfusion
- Automated segmentation of chronic stroke lesions using LINDA: Lesion identification with neighborhood data analysis
- Eigenanatomy
- Corrective learning for segmentation refinement