Computational anatomy of the hippocampus: bridging spatial scales with topological (archi)cortical modelling

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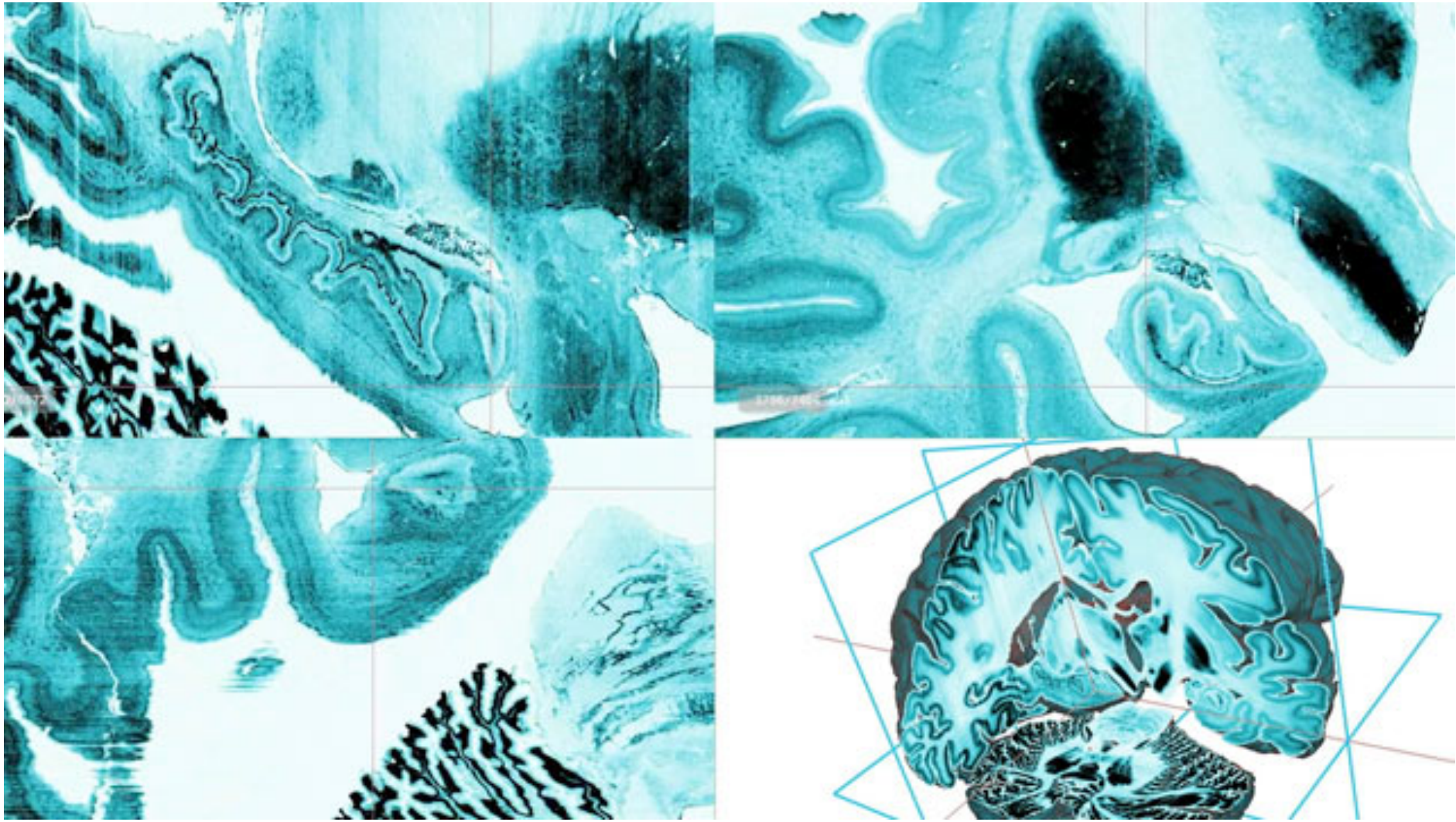
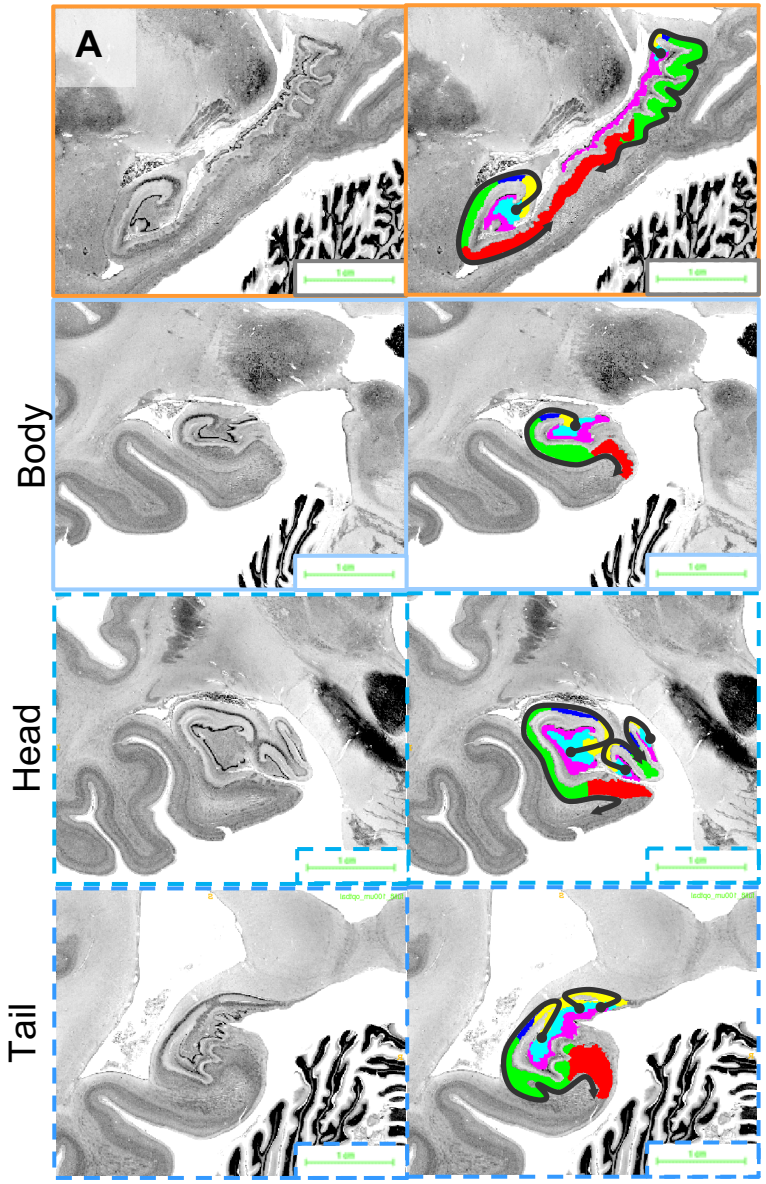
Bridging meso- and micro-scale structure

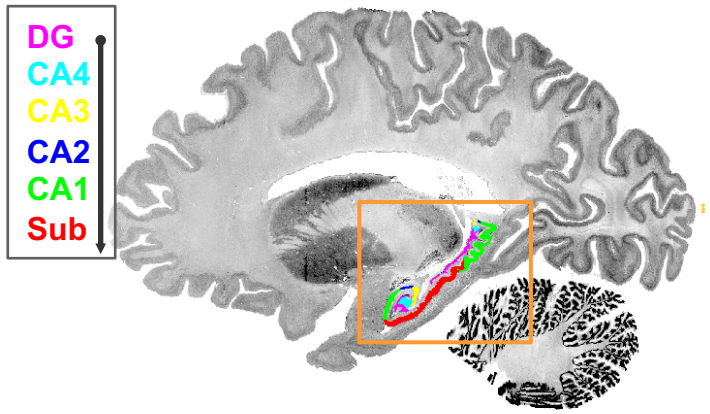
2015 release Hippocampal block (40um) with optical balancing

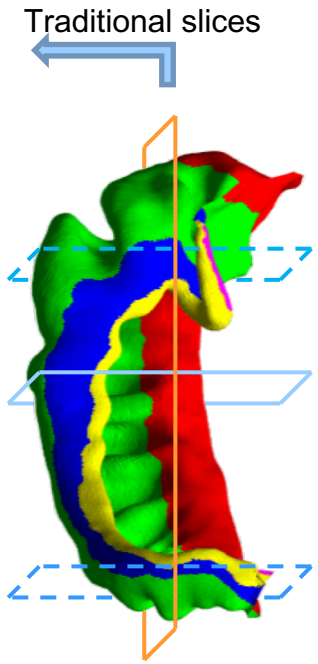


Amunts *et al*., 2015

Subfield segmentation and their topology

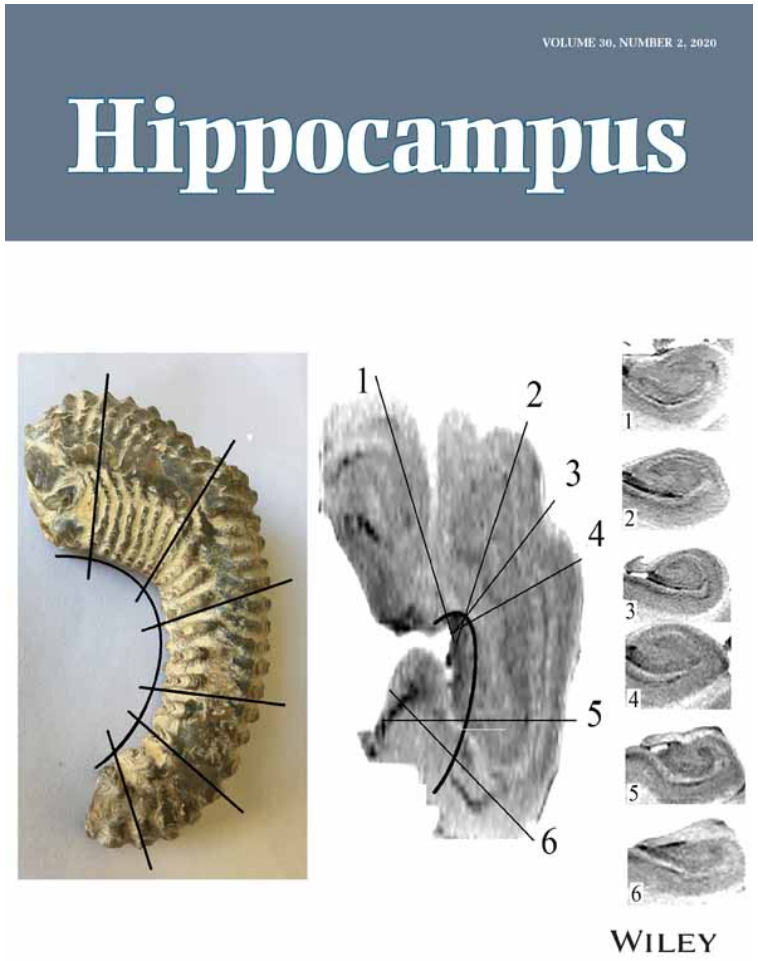




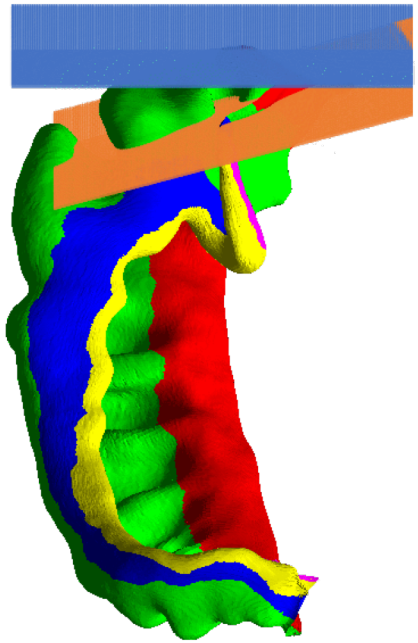


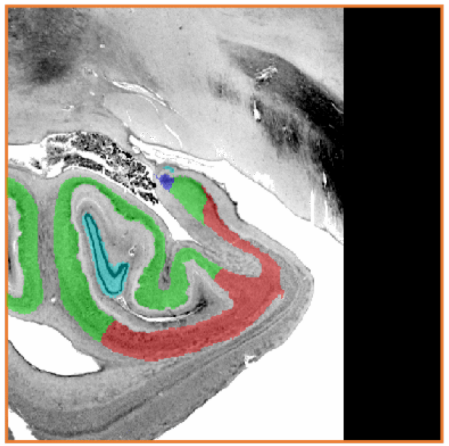
- Note the topological discontinuities seen between subfields in individual slices of the hippocampal head and tail
- Not much consistency, even between nearby slices (especially in head and tail)

3D histology and the out-of-plane problem

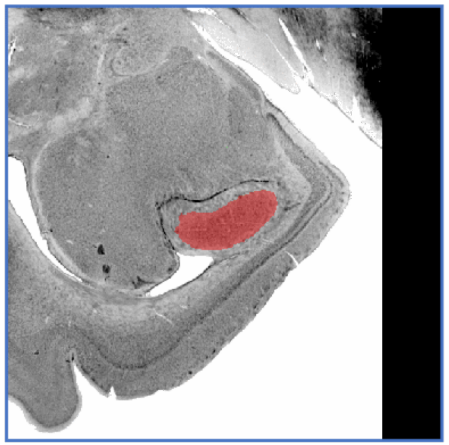


Gross *et al.*, 2020



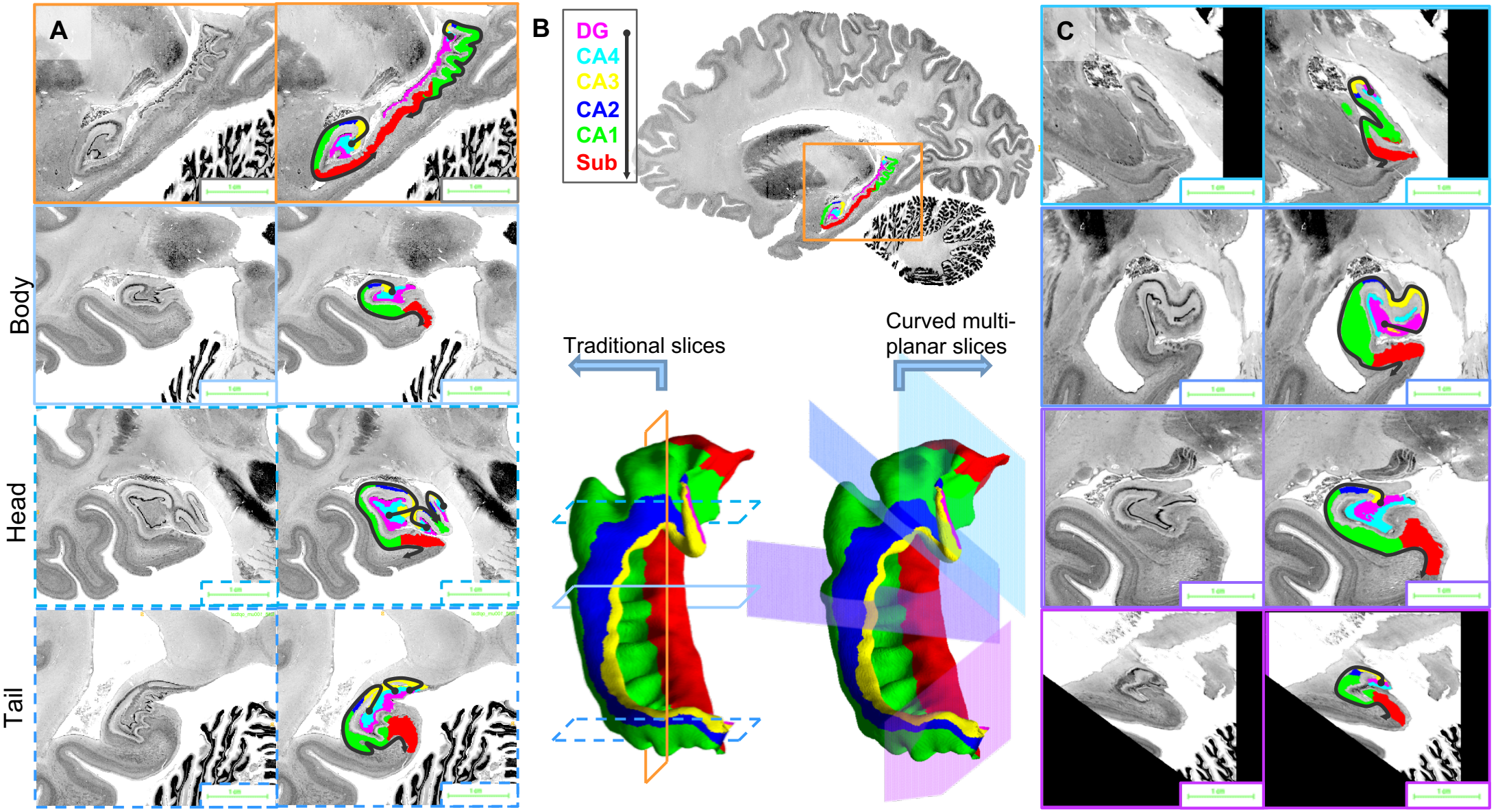


Curved multi-planar slices



Coronal slices

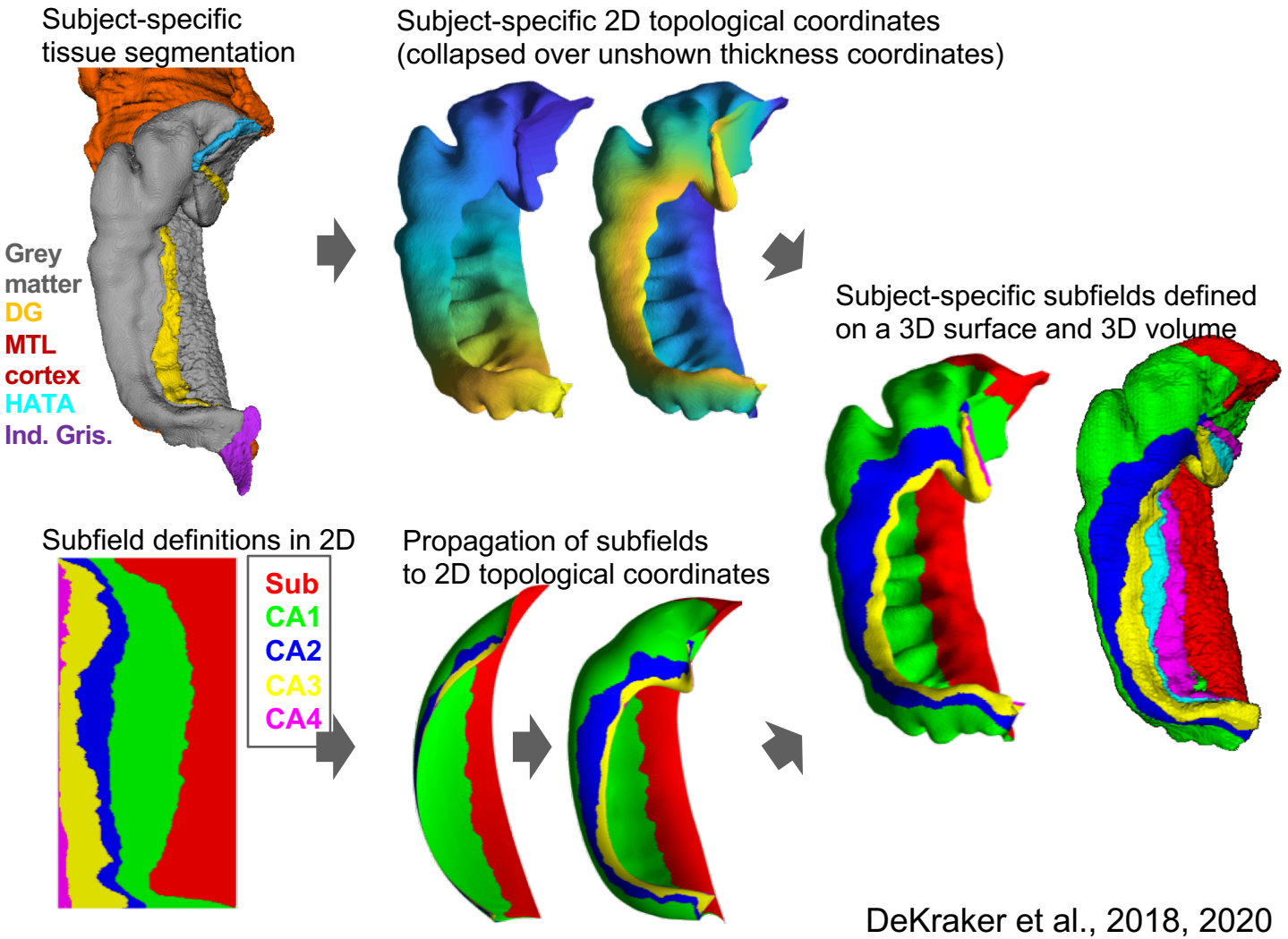
3D histology and the out-of-plane problem



Cumulative summary

- The folding of intrahippocampal tissue is complex, and often out-of-plane in traditional histology (and highly anisotropic MRI)
  - Resampling along the gross curvature of the hippocampus allows higher consistency between all planes
- Unfolding the hippocampus can simplify this problem further still

Intrinsic hippocampal coordinates



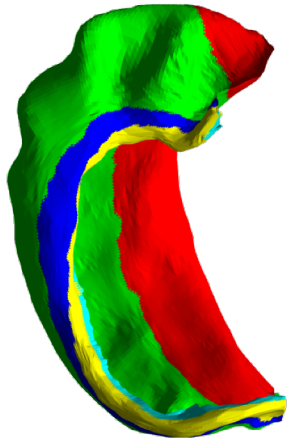
DeKraker et al., 2018, 2020

- **Unfolding advantages:**
  - Contiguous subfields
  - 2D spatial regularizing (e.g. 2D smoothing)
  - Perpendicular columns (ideal for thickness, gyrification index, or laminar measures)

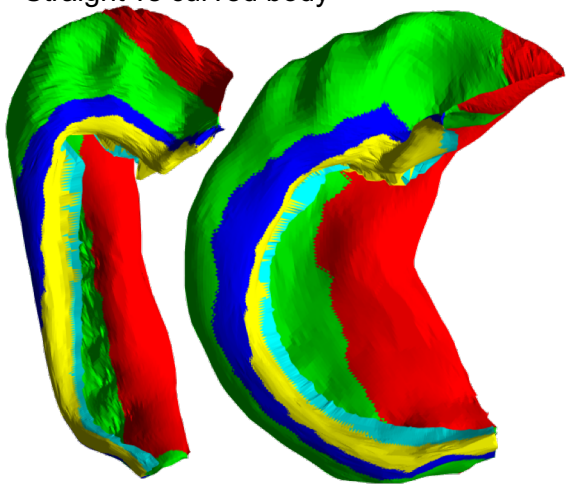
Intrinsic hippocampal coordinates

Between-subject variability
BigBrain boundaries applied to other subjects (UPenn ex-vivo MRI):

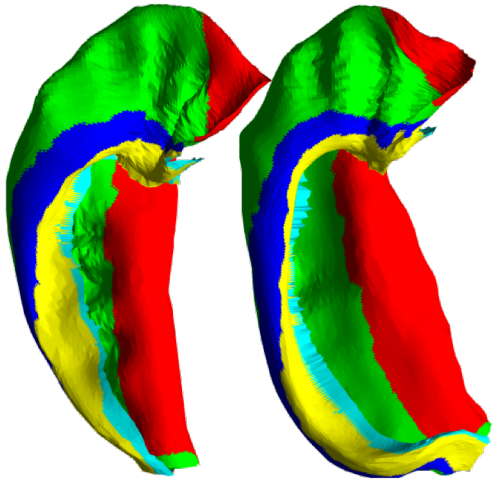
Prototypical



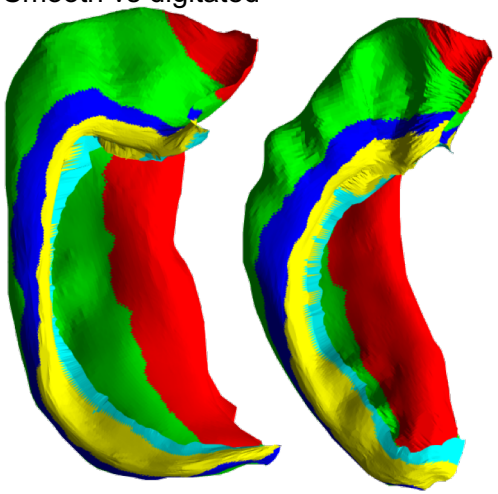
Straight vs curved body



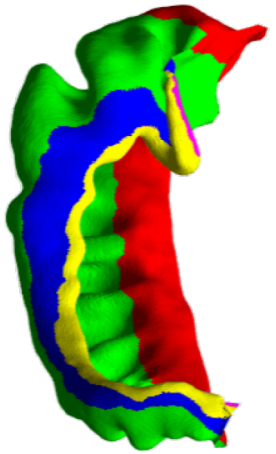
Small vs large tail



Smooth vs digitated



BigBrain reference



- **Unfolding advantages:**
  - Contiguous subfields
  - 2D spatial regularizing (e.g. 2D smoothing)
  - Perpendicular columns (ideal for thickness, gyrification index, or laminar measures)
  - Helps account for inter-individual differences in folding

Cumulative summary

- The folding of intrahippocampal tissue is complex, and often out-of-plane in traditional histology (and highly anisotropic MRI)
  - Resampling along the gross curvature of the hippocampus allows higher consistency between all planes
- Unfolding the hippocampus can simplify this problem further still
  - Accounts for inter-individual differences in folding (especially finer scale digitations)
- The subfield boundaries applied here are not ubiquitous (among histologists or MRI researchers)

Contention & harmonization over subfield definitions

- >20 active segmentation protocols
- Early success in the hippocampal body using anisotropic T2w data
- Major setbacks in the hippocampal head & tail

Hippocampus

Commentary

A harmonized segmentation protocol for hippocampal and parahippocampal subregions: Why do we need one and what are the key goals?

Laura E.M. Wisse, Ana M. Daugherty, Rosanna K. Olsen, David Berron, Valerie A. Carr, Craig E.L. Stark, Robert S.C. Amaral, Katrin Amunts, Jean C. Augustinack, Andrew R. Bender, Jeffrey D. Bernstein, Marina Boccardi, Martina Bocchetta, Alison Burggren, M. Mallar Chakravarty, Marie Chupin, Arne Ekstrom, Robin de Flores, Ricardo Insausti, Prabesh Kanel, Olga Kedo, Kristen M. Kennedy, Geoffrey A. Kerchner, Karen F. LaRocque, Xiuwen Liu, Anne Maass, Nicolai Malykhin, Susanne G. Mueller, Noa Ofen, Daniela J. Palombo, Mansi B. Parekh, John B. Pluta, Jens C. Pruessner, Naftali Raz, Karen M. Rodrigue, Dorothee Schoemaker, Andrea T. Shafer, Trevor A. Steve, Nanthia Suthana, Lei Wang, Julie L. Winterburn, Michael A. Yassa, Paul A. Yushkevich, Renaud la Joie, for the Hippocampal Subfields Group

ELSEVIER

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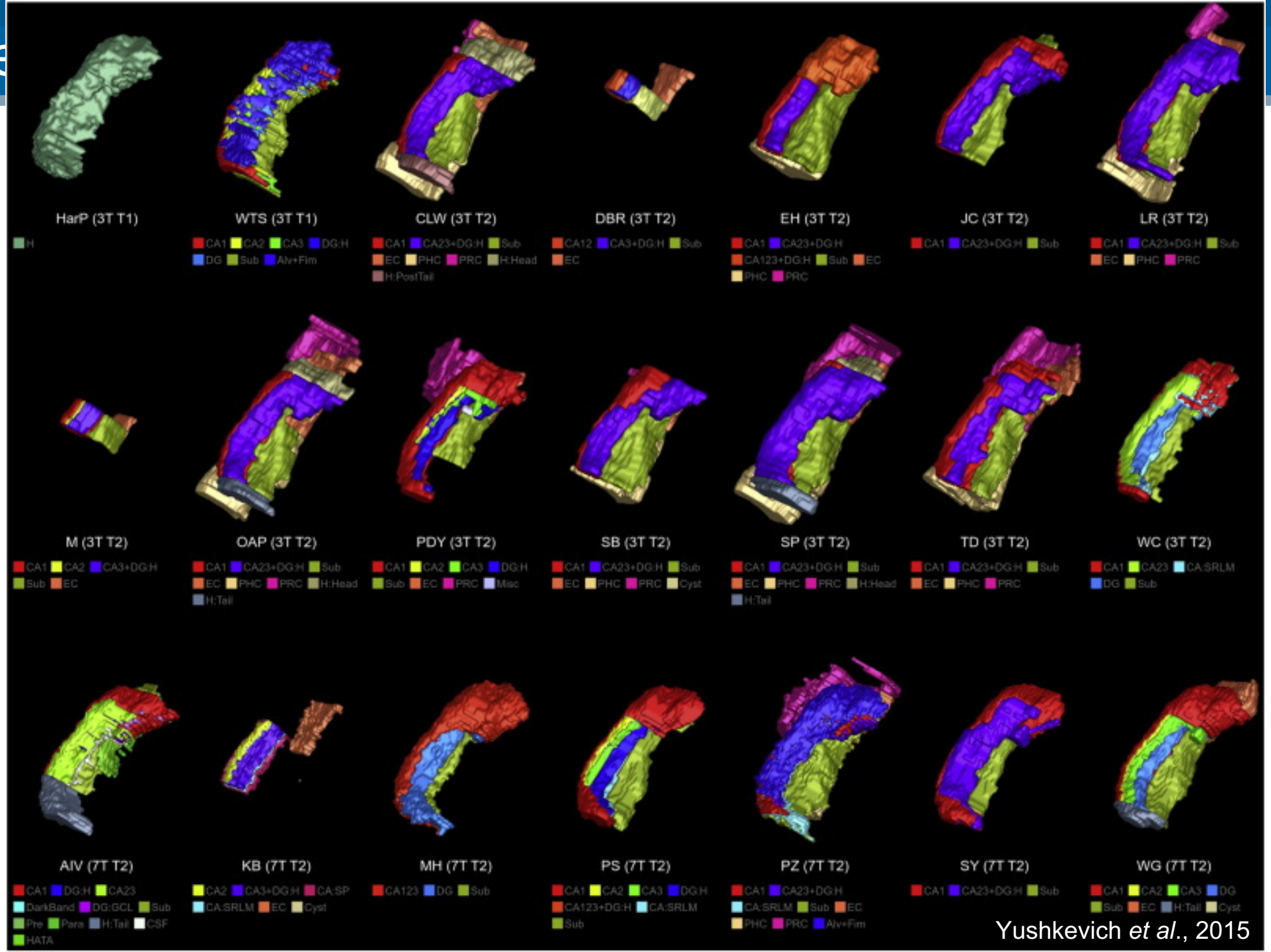
Volume 11, December 2019, Pages 439-449

Working Group Summaries for European Joint Programming For Neurodegenerative Research (JPND)

Progress update from the hippocampal subfields group

Rosanna K. Olsen [a, b], Valerie A. Carr [c], Ana M. Daugherty [d, e, f], Renaud La Joie [g], Robert S.C. Amaral [h], Katrin Amunts [i, j, k], Jean C. Augustinack [l, m], Arnold Bakker [n], Andrew R. Bender [o, p, q], David Berron [r, s], Marina Boccardi [t, u], Martina Bocchetta [v], Alison C. Burggren [w], M. Mallar Chakravarty [h, x, y], Gaël Chételat [z, aa, bb], Robin de Flores [z, aa], Jordan DeKraker [cc], Song-Lin Ding [dd] ... Laura E.M. Wisse [zz, aaa]

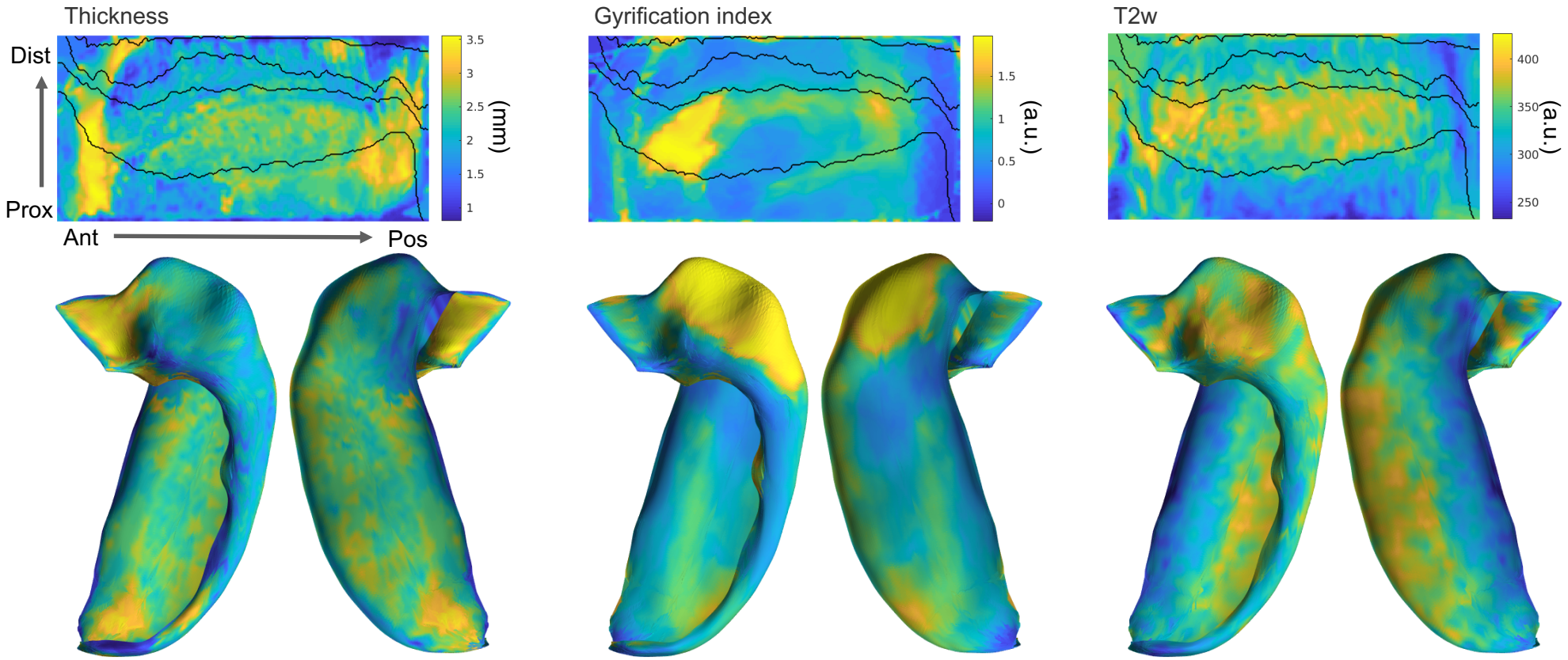
Conte



Yushkevich *et al.*, 2015

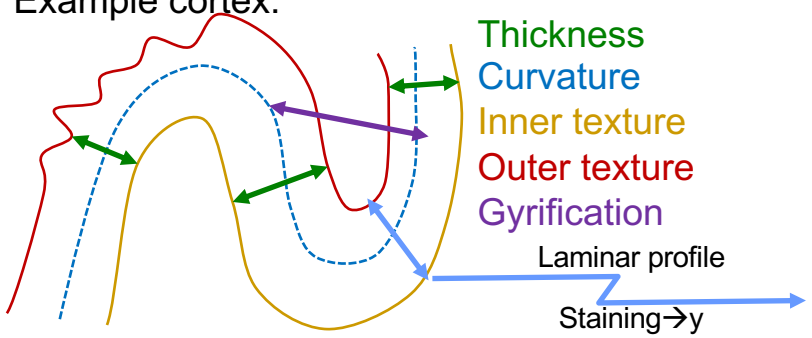
Data-driven segmentation approach

- Example surface-based feature extraction (Human Connectome Project sample subject):

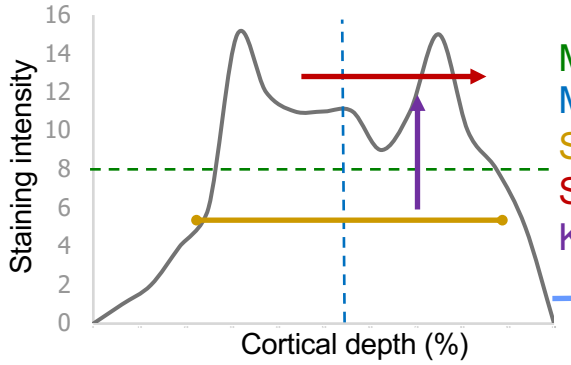


Advanced feature extraction in 3D BigBrain

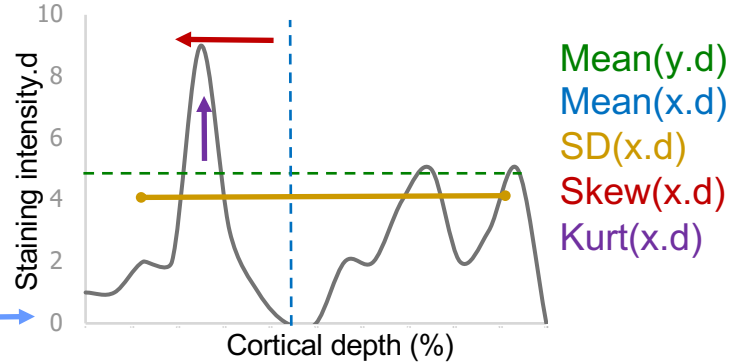
Example cortex:



Waehnert *et al.*, 2014

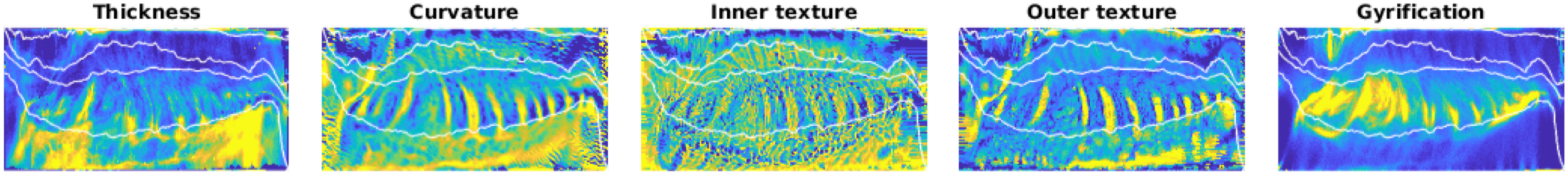


Abs.Deriv.
y→y.d



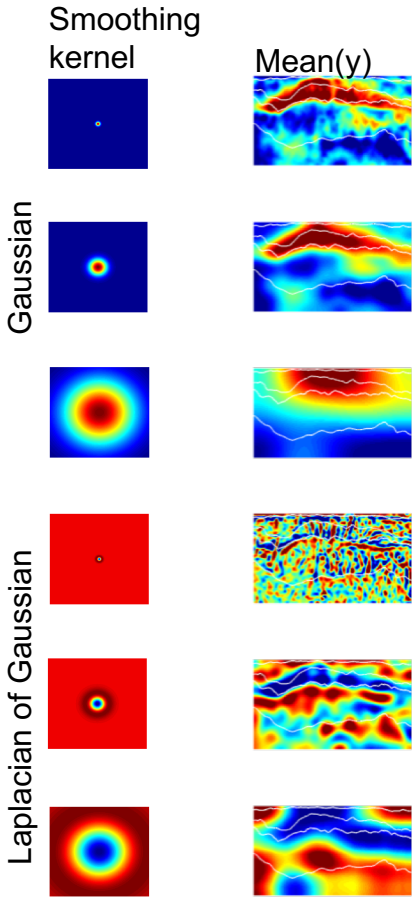
Amunts *et al.*, 1999

Unfolded archicortex:



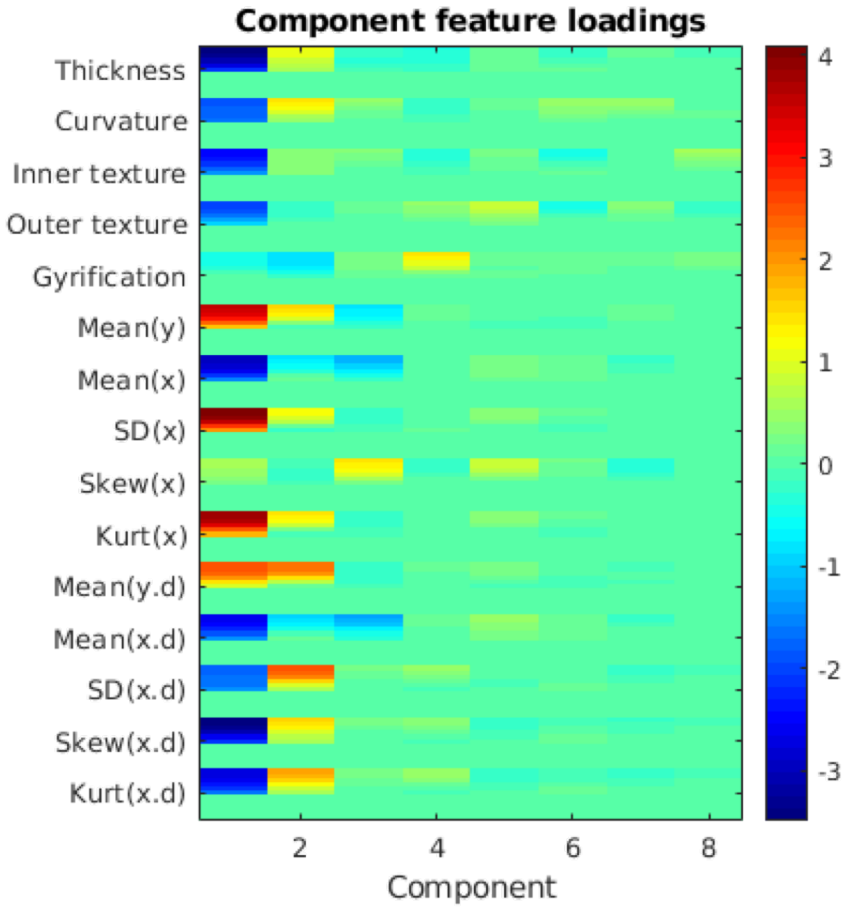
Unsupervised clustering of features

Multi-scale Gaussian processing pyramid



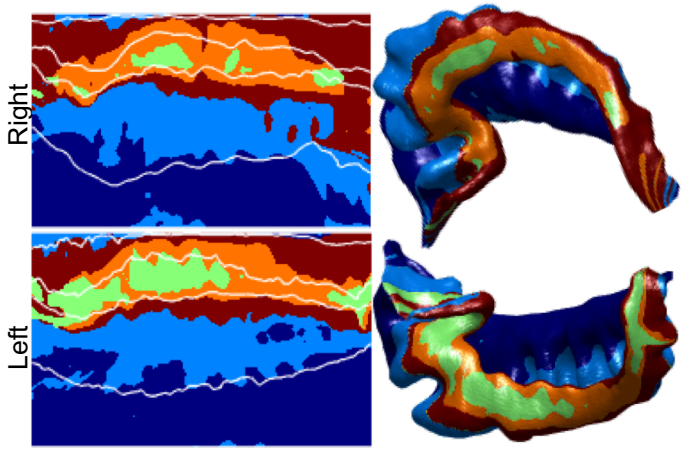
Sigma = [2 4 8 16 32 64]
12 kernels x15 features

Dimensionality reduction (Principle Components Analysis)



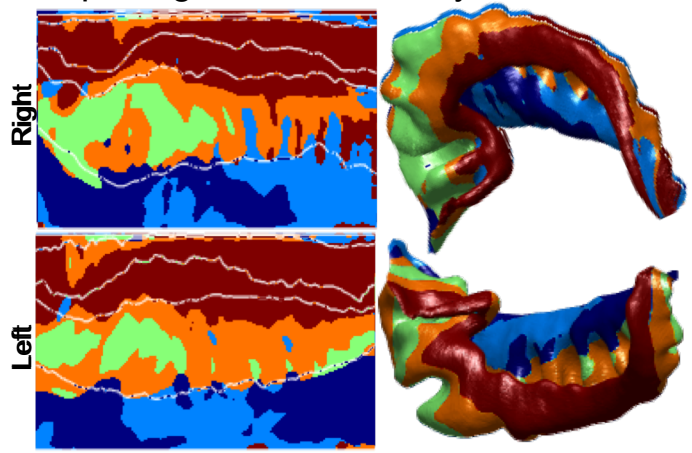
K-means clustering

All features clustered



Laminar features only

Morphological features only



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  - Accounts for inter-individual differences in folding (especially finer scale digitations)
- The subfield boundaries applied here are not ubiquitous (among histologists or MRI researchers)
  - Our data-driven analysis of BigBrain showed high overlap with manual histological definitions

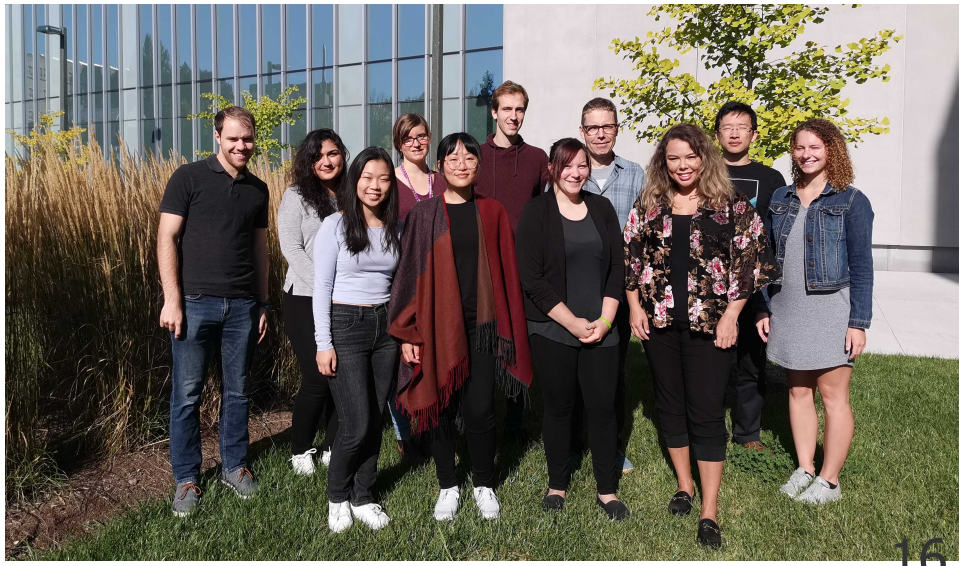
Thanks

Supervisors
Dr. Ali Khan
Dr. Stefan Köhler

Contributors & collaborators
Dr. Jonathan Lau
Dr. Roy Haast
Sara Pac
Mohamed Yousif
Kayla Ferko
Nick Christidis

Advisors
Dr. Jody Culham
Dr. Jörn Diedrichsen

Köhler and Khan lab members



Future work: Improving interpretability in MRI

- Hopefully, after seeing the topology in a high resolution, it should be obvious in a low resolution image
- BIDSapp reveal (UNet workhorse) at OHBM2020 poster 1326!