Child Mind® Institute

big data analytics

C-PAC

TEXAS

The University of Texas at Austin

Penn

University of Pennsylvania

Columbia University

In the City of New York

http://fcp-indi.github.io

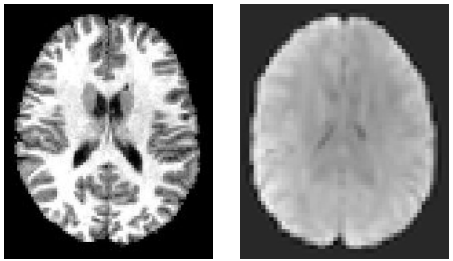
- What is C-PAC?
- Why is C-PAC?
- How does C-PAC work?
- How to run C-PAC in a container?
- Demo

Magnetic Resonance Imaging (MRI)

What's MRI?

- Medical imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body

Why is MRI preprocessing important?



- Remove data collection artifacts
- Prepare for group-level analysis
- Improve computational reproducibility

How is MRI preprocessed?

- Anatomical preprocessing: brain extraction, tissue segmentation, registration
- Functional preprocessing: slice timing correction, motion correction, coregistration, functional image to template warp, spatial smoothing, statiscal analysis

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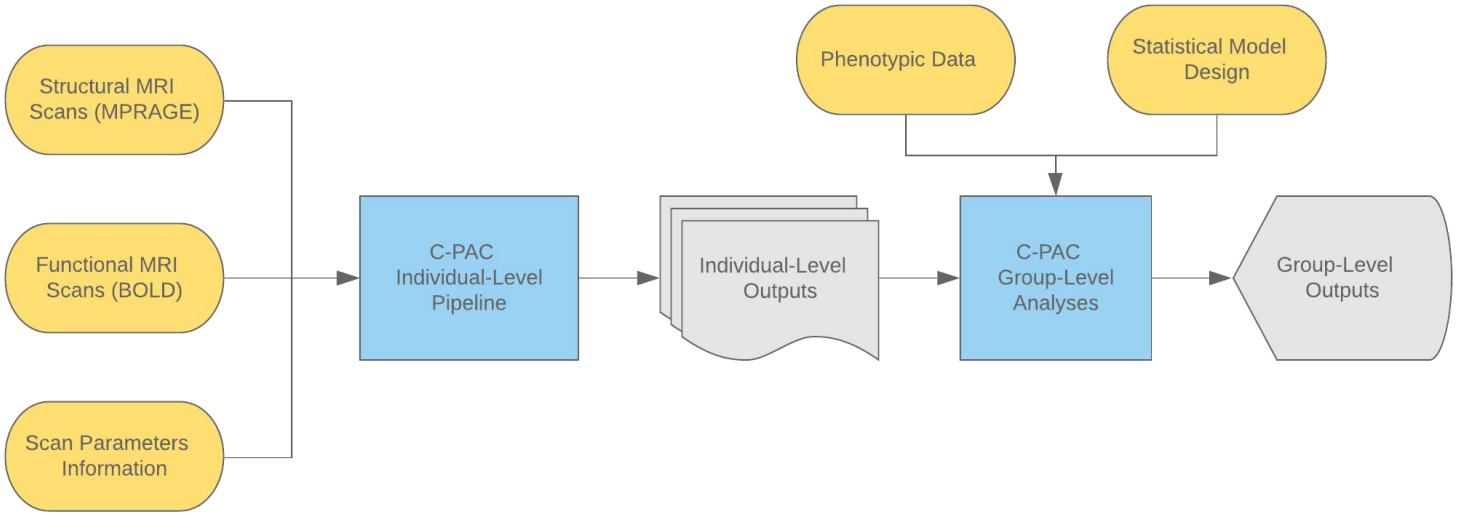
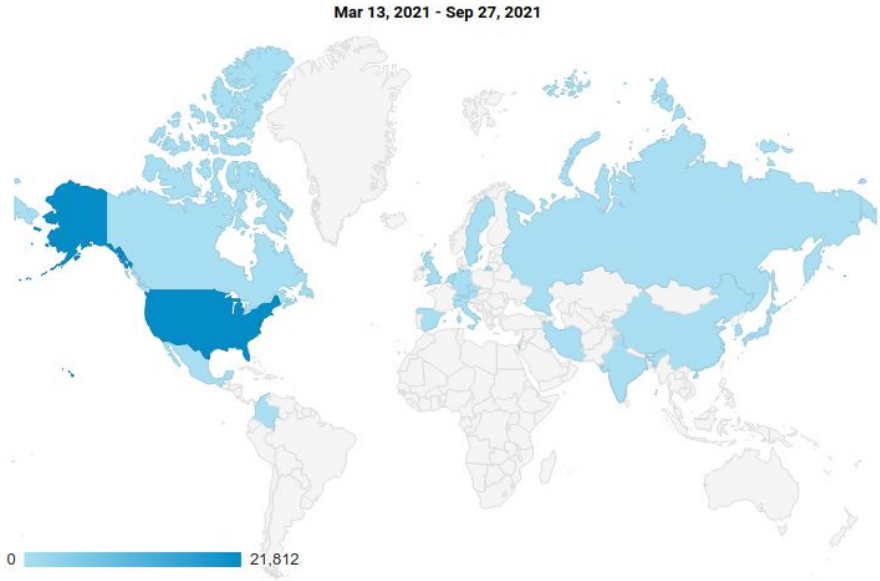
C-PAC Overview

- **C-PAC** (Configurable Pipeline for the Analysis of Connectomes)
  - An open-source **functional connectomics package**
  - Designed for ease-of-use (no programming required), but also deep configurability
  - The C-PAC pipeline employs many common neuroimaging tools (AFNI, FSL, ITK/ANTs, C3d etc.) and Python-based neuroimaging packages (PyBASC, PyPEER etc.)



World-wide Usage



Country	Acquisition Users
	81,872 % of Total: 100.00% (81,872)
1. United States	53,946 (65.79%)
2. China	3,279 (4.00%)
3. Germany	2,715 (3.31%)
4. United Kingdom	2,128 (2.60%)
5. India	1,831 (2.23%)
6. Canada	1,797 (2.19%)
7. Japan	1,483 (1.81%)
8. Netherlands	1,174 (1.43%)
9. Italy	1,163 (1.42%)
10. South Korea	864 (1.05%)

Academic Usage

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

Deriving reproducible biomarkers from multi-site resting-state data: An Autism-based example

Alexandre Abraham[a,b,*], Michael P. Milham[e,f], Adriana Di Martino[g], R. Cameron Craddock[e,f], Dimitris Samaras[c,d], Bertrand Thirion[a,b], Gael Varoquaux[a,b]

[a] Parietal Team, Saclay-INRIA Ile-de-France,Saclay,France
[b] CEA, Neurospin bât 145, 91191 Gif-Sur-Yvette, France
[c] Stony Brook University, NY 11794, USA
[d] Ecole Centrale, 92290 Châtenay Malabry, France
[e] Center for the Developing Brain, Child Mind Institute, New York, USA
[f] Center for Biomedical Imaging and Neuromodulation, Nathan S. Kline Institute for Psychiatric Research, Orangeburg, NY, USA
[g] The Child Study Center at NYU Langone Medical Center, New York, USA

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

Benchmarking functional connectome-based predictive models for resting-state fMRI

Kamalaker Dadi[a,b,*], Mehdi Rahim[a,b], Alexandre Abraham[a,b], Darya Chyzhyk[a,b,c], Michael Milham[c], Bertrand Thirion[a,b], Gaël Varoquaux[a,b], for the Alzheimer's Disease Neuroimaging Initiative[1]

[a] Parietal Project-team, INRIA Saclay-Ile de France, France
[b] CEA/Neurospin bât 145, 91191, Gif-Sur-Yvette, France
[c] Center for the Developing Brain Child Mind Institute, Center for Biomedical Imaging and Neuromodulation, Nathan S. Kline Institute for Psychiatric Research, USA

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

The real-time fMRI neurofeedback based stratification of Default Network Regulation Neuroimaging data repository

Amalia R. McDonald[a], Jordan Muraskin[a], Nicholas T.Van Dam[a,b], Caroline Froehlich[a], Benjamin Puccio[a], John Pellman[b], Clemens C.C. Bauer[c], Alexis Akeyson[a], Melissa M. Breland[a], Vince D. Calhoun[d,e], Steven Carter[a], Tiffany P. Chang[a], Chelsea Gessner[a], Alyssa Gianonne[a], Steven Giavasis[b], Jamie Glass[a], Steven Homann[a], Margaret King[a], Melissa Kramer[a], Drew Landis[d], Alexis Lieval[a], Jonathan Lisinski[f], Anna Mackay-Brandt[a,g], Brittny Miller[d], Laura Panek[a], Hayley Reed[a], Christine Santiago[a], Eszter Schoell[a], Richard Sinnig[a], Melissa Sital[a], Elise Taverna[a], Russell Tobe[a], Kristin Trautman[a], Betty Varghese[a], Lauren Walden[a], Runtang Wang[d], Abigail B. Waters[a], Dylan C. Wood[d], F.Xavier Castellanos[a,h], Bennett Leventhal[i], Stanley J. Colcombe[a], Stephen LaConte[d,j,k], Michael P. Milham[a,b], R.Cameron Craddock[a,b,*]

[a] Nathan Kline Institute for Psychiatric Research, Orangeburg, NY, USA
[b] Child Mind Institute, New York, NY, USA
[c] Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Boston, MA, USA
[d] The Mind Research Network, Albuquerque, New Mexico, USA
[e] Department of Electrical and Computer Engineering, The University of New Mexico, Albuquerque, New Mexico, USA
[f] Virginia Tech Carilion Research Institute, Roanoke, VA, USA
[g] Columbia University, Cognitive Neuroscience Division, Taub Institute and GH Sergeievsky Center, New York, NY, USA
[h] The Child Study Center, NYU Langone Medical Center, New York, NY, USA
[i] Department of Psychiatry, University of California - San Francisco, San Francisco, CA, USA
[j] School of Biomedical Engineering and Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA
[k] Departments of Emergency Medicine and Emergency Radiology, Virginia Tech Carilion School of Medicine, Roanoke, VA, USA

Contents lists available at ScienceDirect

Medical Image Analysis

journal homepage: www.elsevier.com/locate/media

Disease prediction using graph convolutional networks: Application to Autism Spectrum Disorder and Alzheimer's disease

Sarah Parisot[b,1,2,*], Sofia Ira Ktena[a,1], Enzo Ferrante[c], Matthew Lee[a], Ricardo Guerrero[d,3], Ben Glocker[a], Daniel Rueckert[a]

[a] Biomedical Image Analysis Group, Imperial College London, UK
[b] AimBrain Solutions Ltd, London, UK
[c] Research Institute for Signals, Systems and Computational Intelligence, sinc(i), FICH-UNL/CONICET, Santa Fe, Argentina
[d] StorySream Ltd., London, UK

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

Optimising network modelling methods for fMRI

Usama Pervaiz[a,*], Diego Vidaurre[b,c], Mark W. Woolrich[b], Stephen M. Smith[a]

[a] Oxford Centre for Functional MRI of the Brain (FMRIB), Wellcome Centre for Integrative Neuroimaging, Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford, OX3 9DU, United Kingdom
[b] Oxford Centre for Human Brain Activity (OHBA), Wellcome Centre for Integrative Neuroimaging, Department of Psychiatry, University of Oxford, Oxford, OX3 7JX, United Kingdom
[c] Department of Clinical Medicine, Aarhus University, Denmark

Contents lists available at ScienceDirect

Journal of Affective Disorders

journal homepage: www.elsevier.com/locate/jad

Research paper

A pilot resting-state functional connectivity study of the kynurenine pathway in adolescents with depression and healthy controls

Samuel J. DeWitt[a,d], Kailyn A. Bradley[a,d], Na Lin[b], Chunli Yu[b], Vilma Gabbay[a,c,*]

[a] Department of Psychiatry, Icahn School of Medicine at Mount Sinai, New York, NY, USA
[b] Department of Genetics and Genomic Sciences Icahn School of Medicine at Mount Sinai, New York, NY, USA
[c] Department of Neuroscience, Icahn School of Medicine at Mount Sinai, New York, NY, USA
[d] Nathan S. Kline Institute for Psychiatric Research, Orangeburg, NY, USA

ORIGINAL ARTICLE

Evaluating fMRI-Based Estimation of Eye Gaze During Naturalistic Viewing

Jake Son[1,2], Lei Ai[1], Ryan Lim[3], Ting Xu[1], Stanley Colcombe[3], Alexandre Rosa Franco[1,3], Jessica Cloud[3], Stephen LaConte[4], Jonathan Lisinski[4], Arno Klein[1,2], R. Cameron Craddock[1,3,5] and Michael Milham[1,3,*]

[1]Center for the Developing Brain, Child Mind Institute, New York, NY 10022, USA, [2]MATTER Lab, Child Mind Institute, New York, NY 10022, USA, [3]Center for Biomedical Imaging and Neuromodulation, Nathan S. Kline Institute for Psychiatric Research, New York, NY 10962, USA, [4]Fralin Biomedical Research Institute, Virginia Tech Carilion Research Institute, Blacksburg, VA 24016, USA and [5]Department of Diagnostic Medicine, Dell Medical School, Austin, TX 78701, USA

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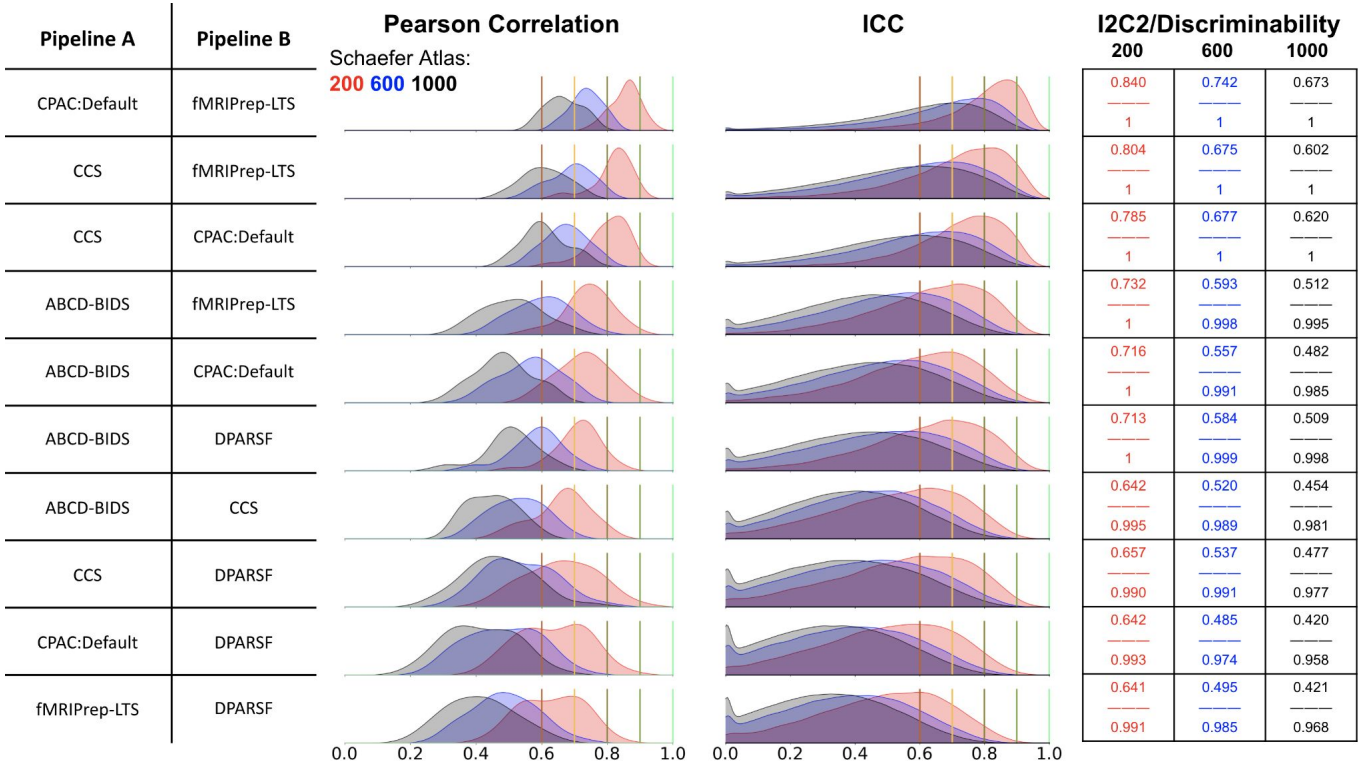
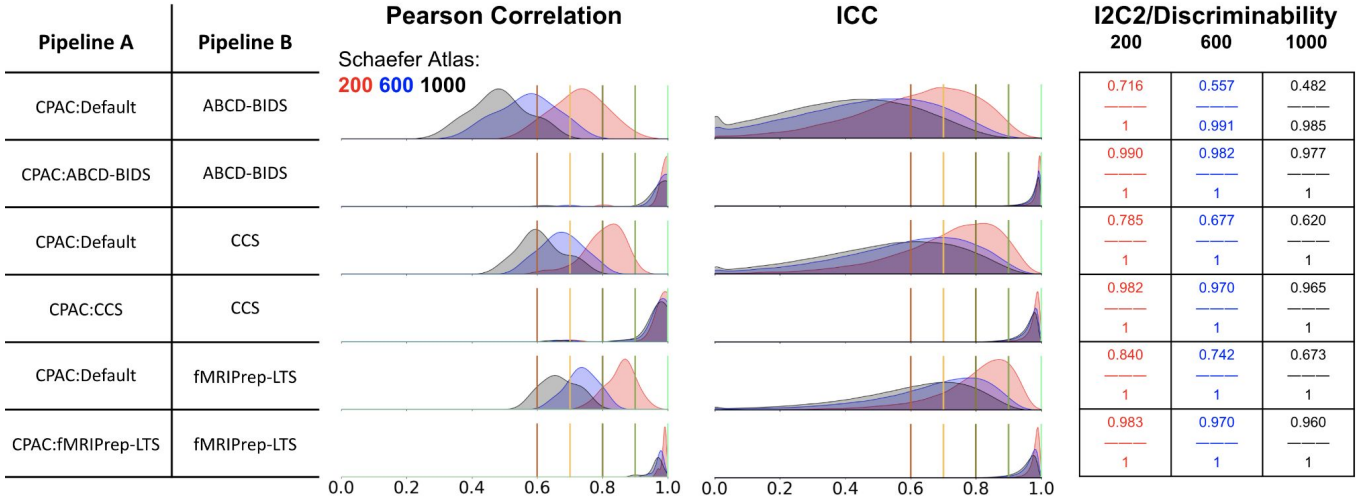
Minimal Preprocessing



Li et al. (in prep)

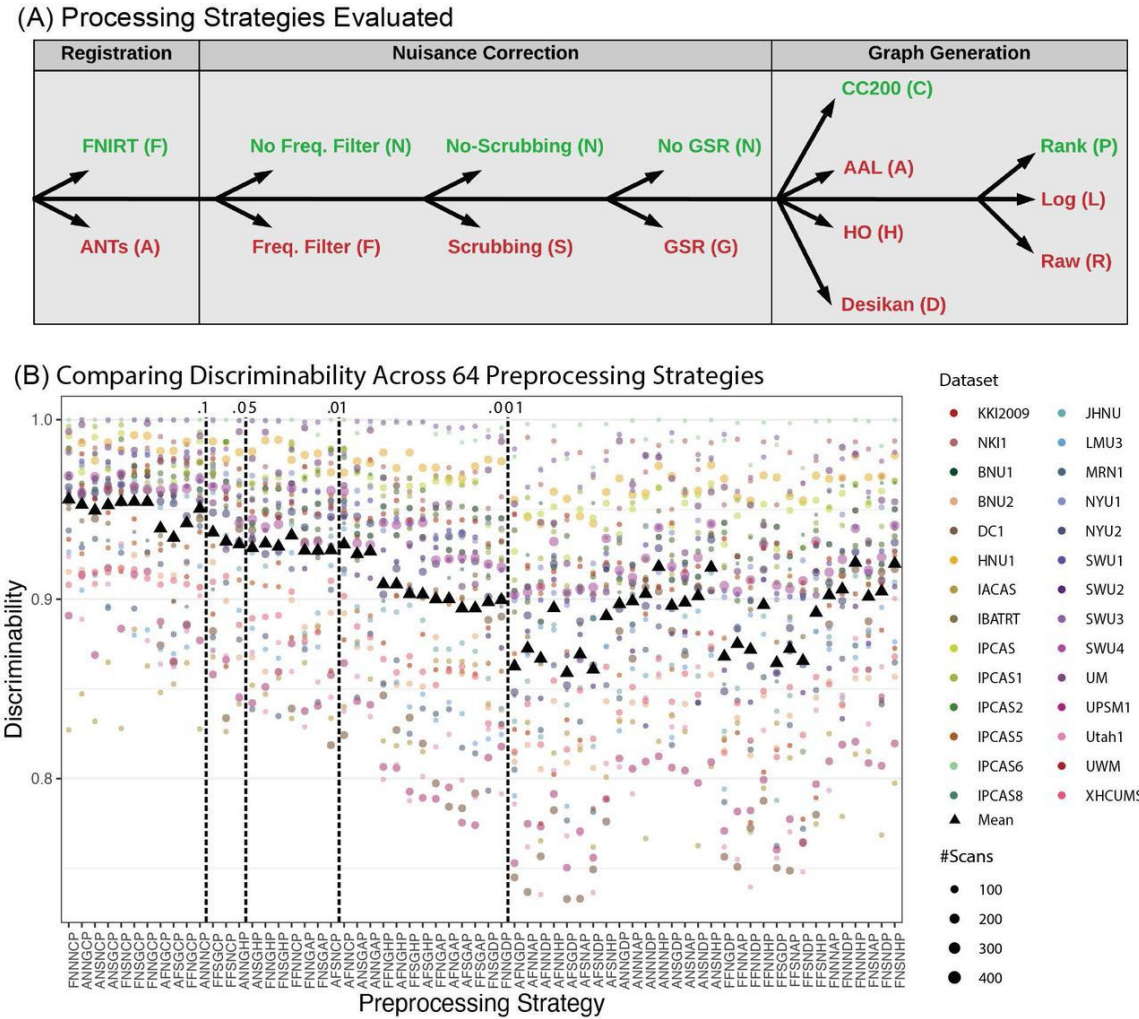
Harmonized Minimal Preprocessing



Li et al. (in prep)

Configurable

Fully customize your pipeline

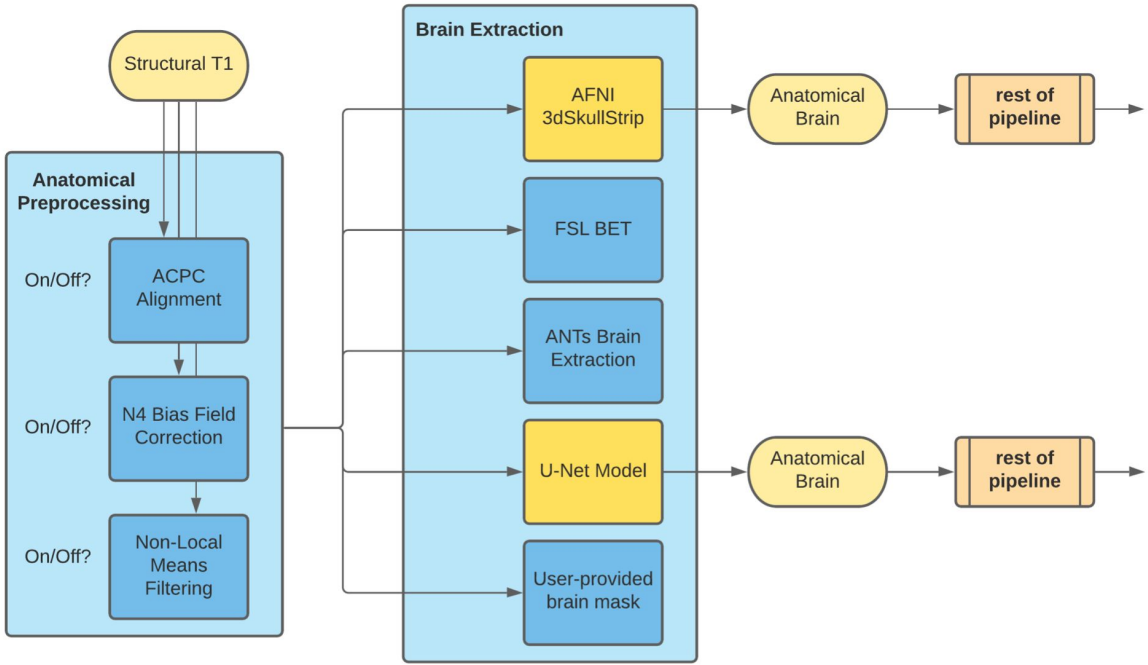


Bridgeford et al. 2021

Forking - On, Off, and On/Off

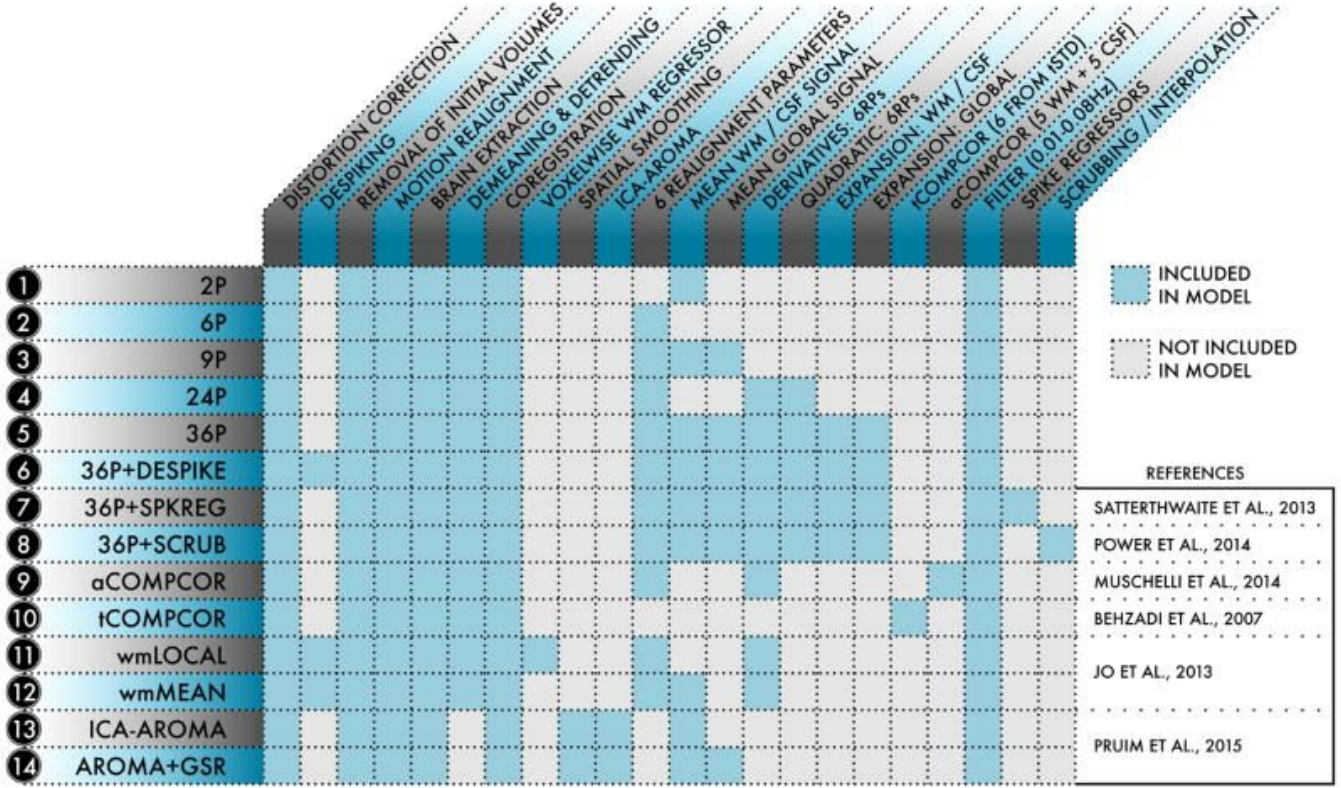
Forkable

Provide fork options, parallelize forks with multiple CPUs



Forkable

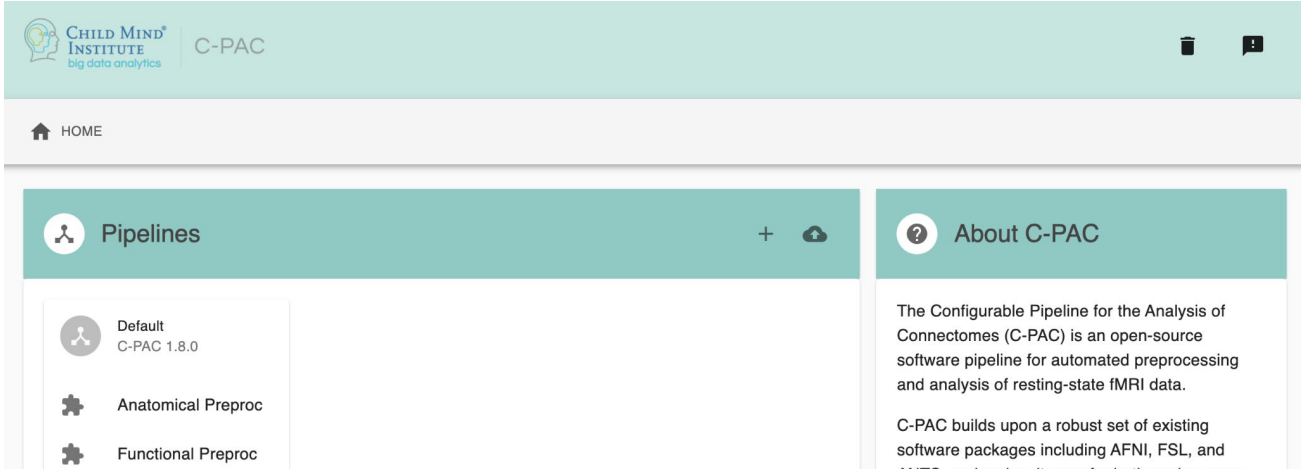
Provide fork options, parallelize forks with multiple CPUs



Ciric et al. 2021

Easy-of-use

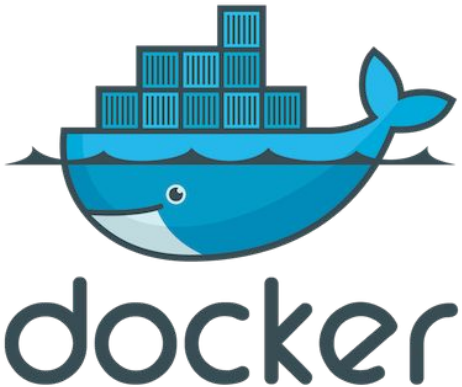
- GUI
- Text-based YAML file can be easily share with others.



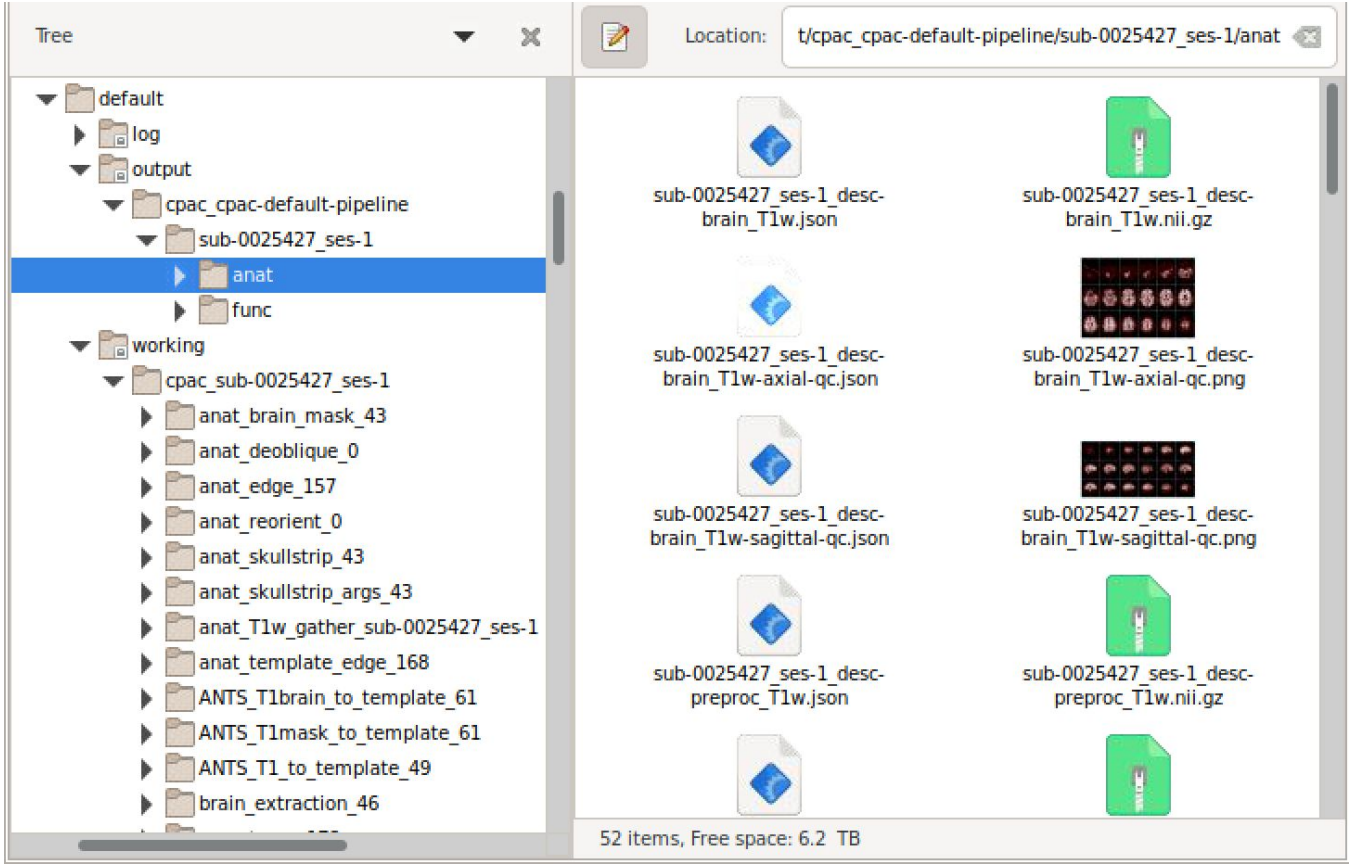
https://fcp-indi.github.io/C-PAC_GUI/versions/nightly/browser/#/

```
anatomical_preproc:
  run: On
  brain_extraction:
    run: On
    using:
      - 3dSkullStrip
      - BET
```

Standardized
Environment



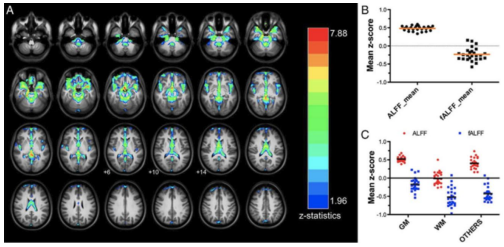
Warm Restart



End-to-end Preprocessing

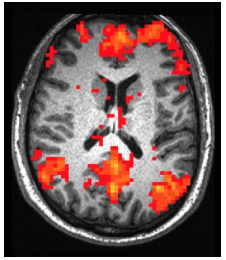
Amplitude of Low Frequency Fluctuations (ALFF) and fractional ALFF (f/ALFF)

Zang et al., 2007. Cited by 1982
Zou et al., 2008. Cited by 1242



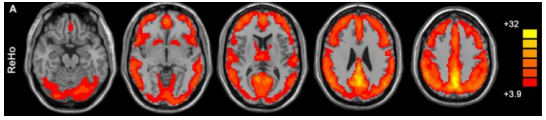
Seed-based Correlation Analysis (SCA)

Biswal et al., 1995. Cited by 8935



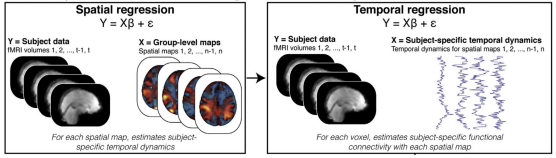
Regional Homogeneity (ReHo)

Zang et al., 2004. Cited by 1841



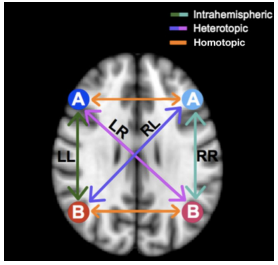
Dual Regression

Beckmann et al., 2009. Cited by 651
Filippini et al., 2009. Cited by 1635



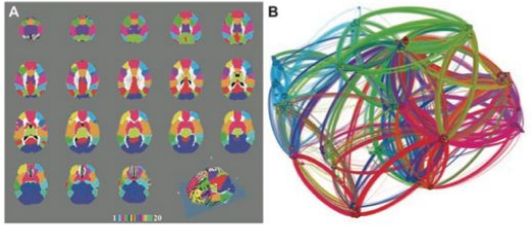
Voxel-Mirrored Homotopic Connectivity (VMHC)

Stark et al., 2008. Cited by 241
Zuo et al., 2010. Cited by 549



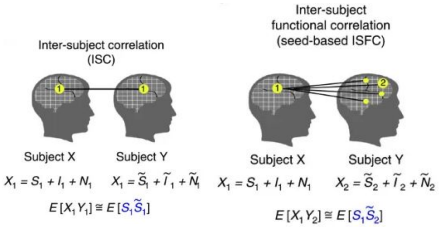
Network Centrality

Buckner et al., 2009. Cited by 2476
Bullmore and Sporns, 2009. Cited by 9619



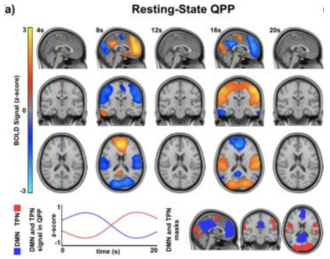
Innovative Analysis

Intersubject Correlation Analyses (ISC) and Inter-subject Functional Correlation (ISFC)



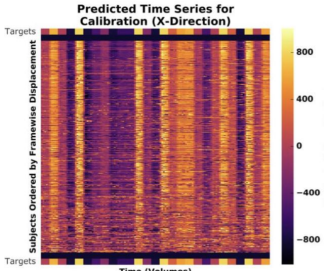
Simony et at., 2016.

Quasi-Periodic Pattern Analysis (QPP)



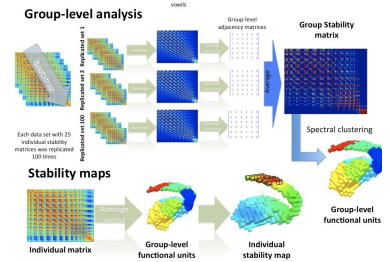
Abbas et al., 2019

Predictive Eye Estimate Regression (PEER)



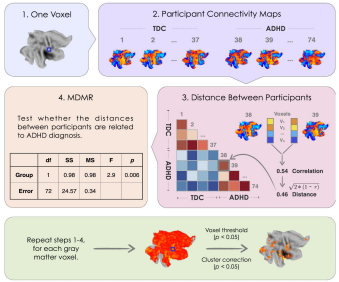
Son et al., 2020.

Bootstrap Analysis of Stable Clusters (BASC)



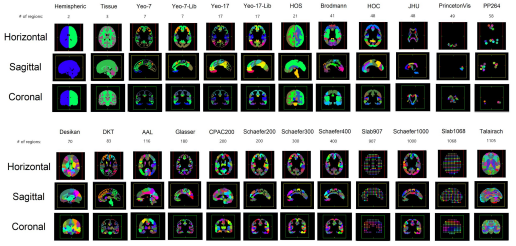
Bellec et al., 2010.

Multivariate Distance Matrix Regression (MDMR)



Shehzad et al., 2014

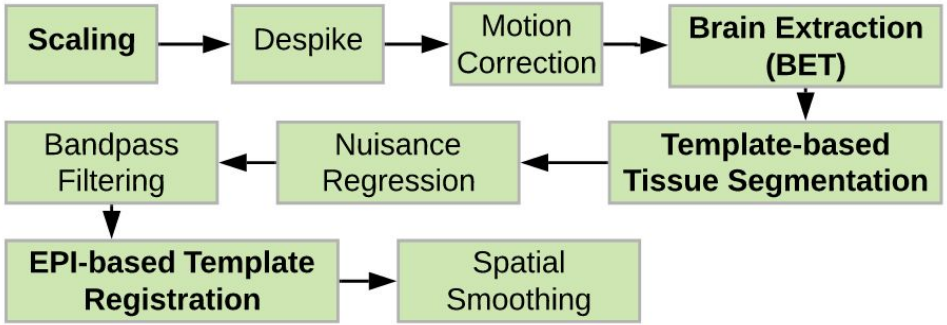
Automated Atlas Extraction (Neuroparc Library)



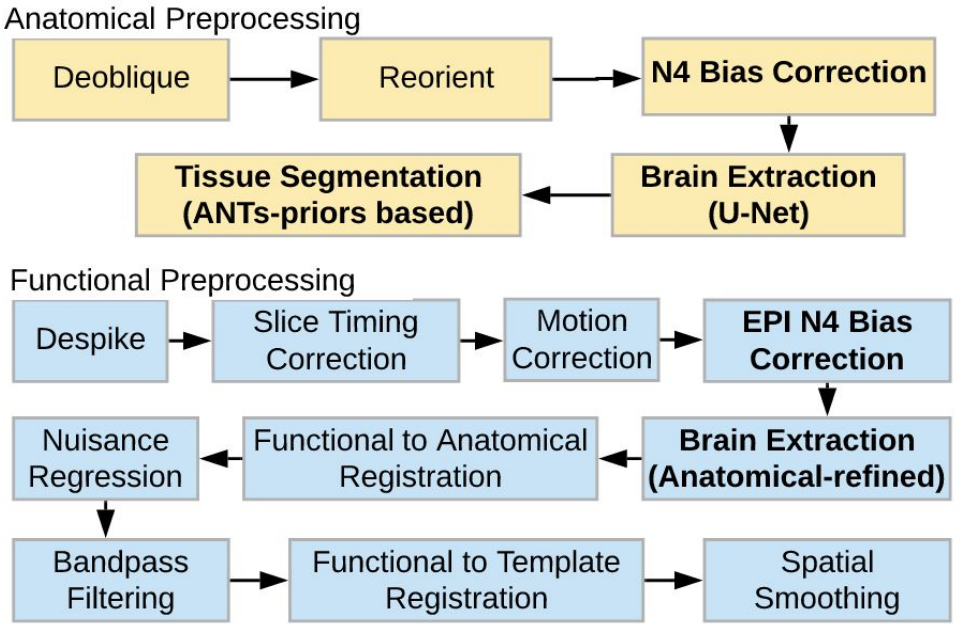
NeuroData, 2020

Non-human Preprocessing

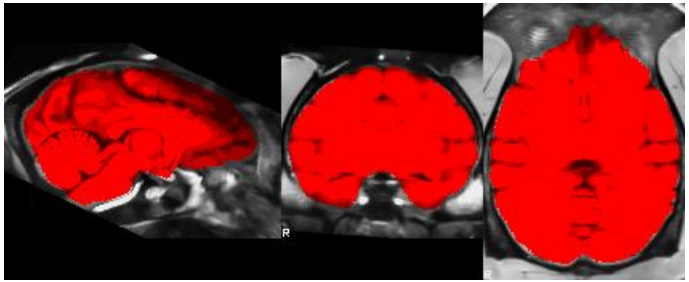
Rodent



Macaque



Jin et al., 2020 OHBM



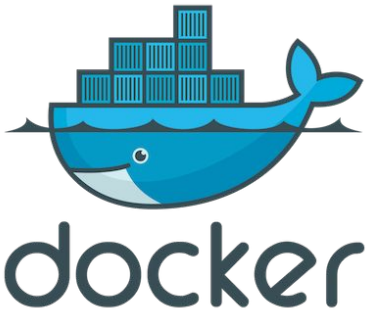
Wang et al., 2021

...then how do you run C-PAC?

Get Running Fast

Quickly pull and run C-PAC via Docker and Singularity containers.

- No need to install anything except Docker or Singularity.
- Self-contained replicated environments for reproducibility.
- *>> docker pull fcpindi/c-pac:latest*



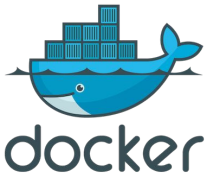
Get Running Big

Spin up big analyses on the cloud using Amazon Web Services (AWS).

- No need to install anything - only needs an AWS account.
- Large variety of performance and space options available depending on budget.
- C-PAC AMI available publicly on the Amazon AMI Marketplace.

How to run C-PAC?

>> docker run <dir mapping> <container image>




```
docker pull fcpindi/c-pac:latest
```

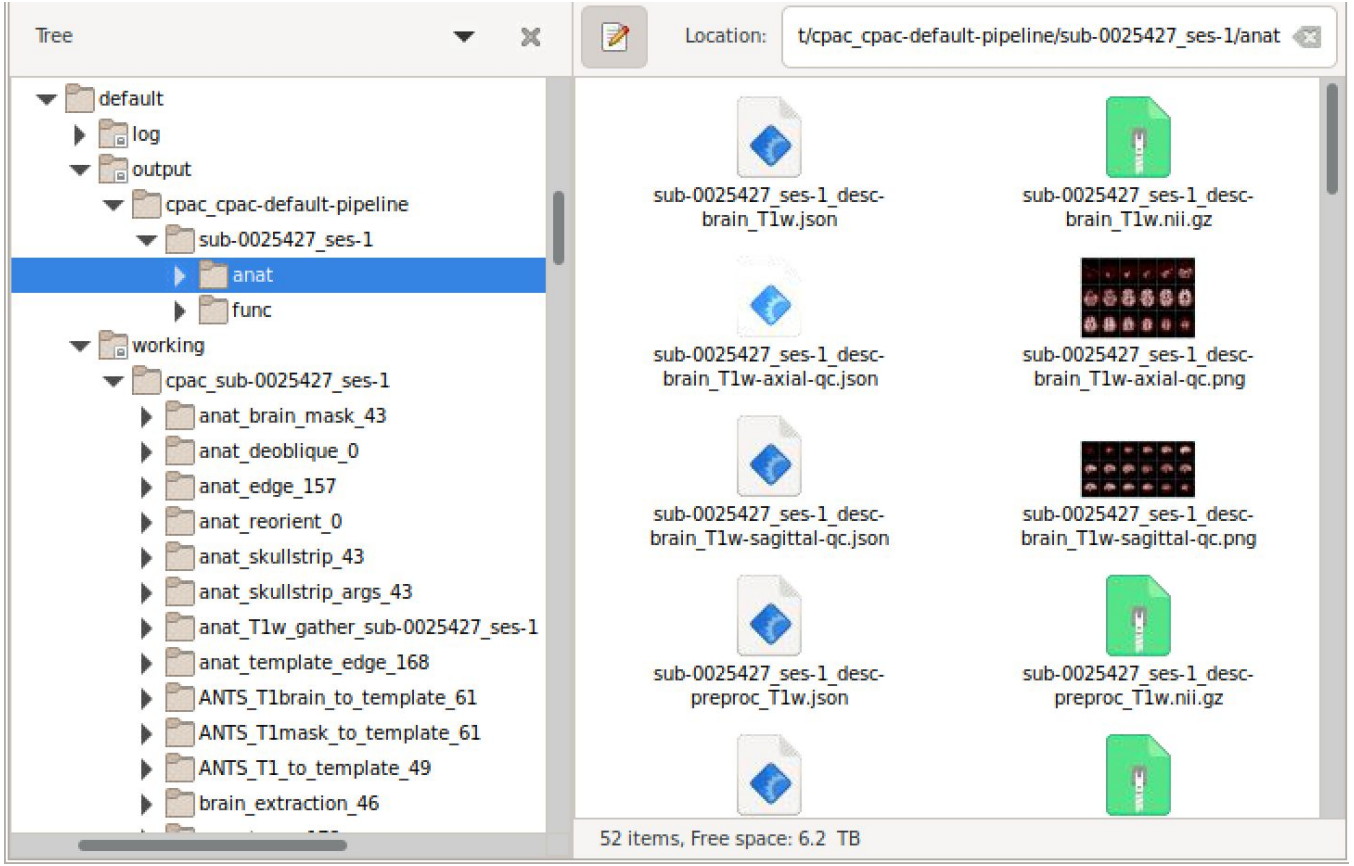
```
docker run -i --rm \
        -v /Users/You/local_bids_data:/bids_dataset \
        -v /Users/You/some_folder:/outputs \
        -v /tmp:/scratch \
        fcpindi/c-pac:latest /bids_dataset /outputs participant
```

>> singularity run <dir mapping> <container image>

```
singularity pull shub://FCP-INDI/C-PAC
```

```
singularity run \
        -B /Users/You/local_bids_data:/bids_dataset \
        -B /Users/You/some_folder:/outputs \
        -B /tmp:/scratch \
        FCP-INDI-C-PAC-master-latest.simg /bids_dataset /outputs participant
```

Get Output
(BIDS derivatives)



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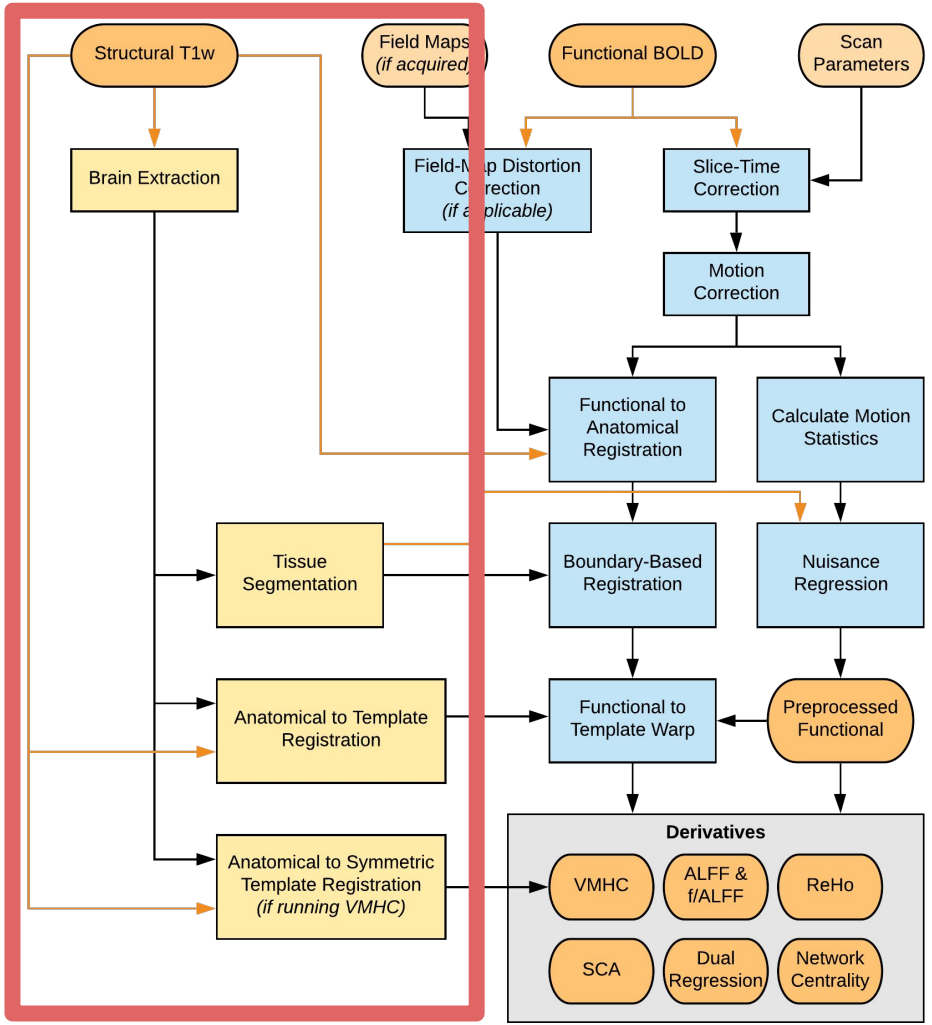
Anatomical Preprocessing



Anatomical Preprocessing: Brain Extraction

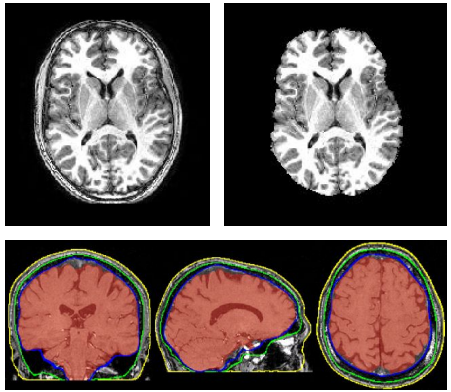
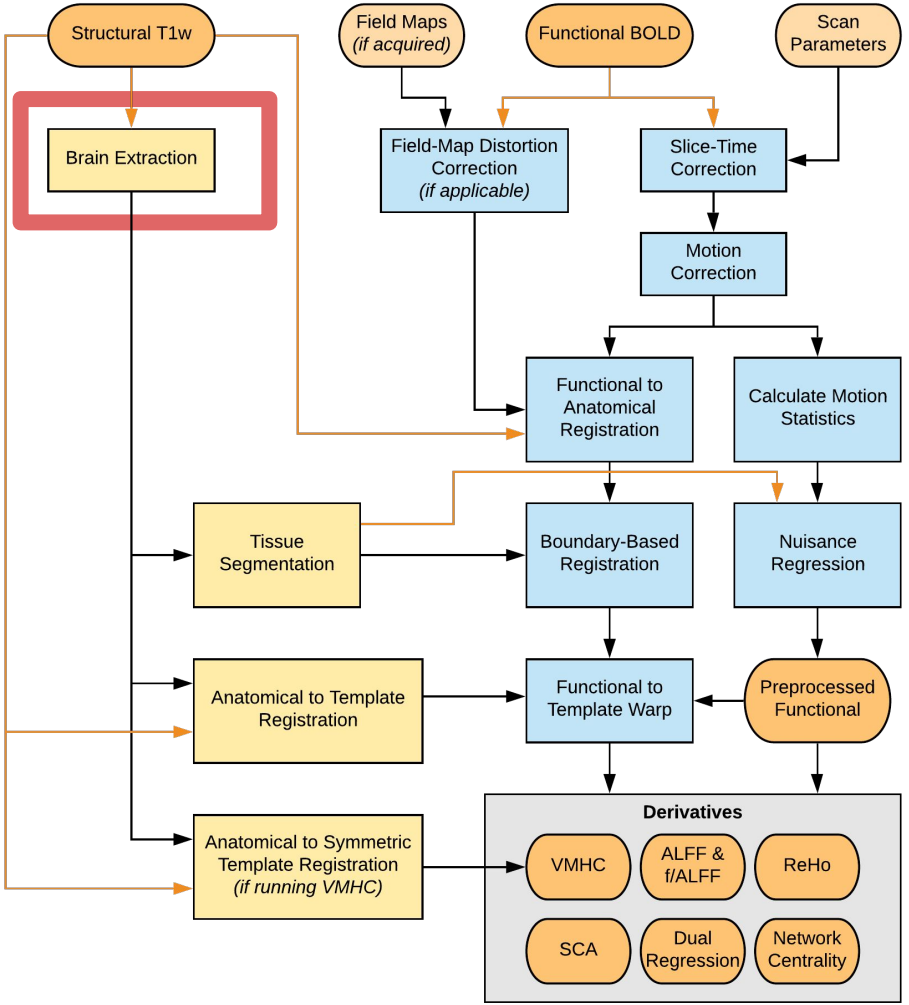
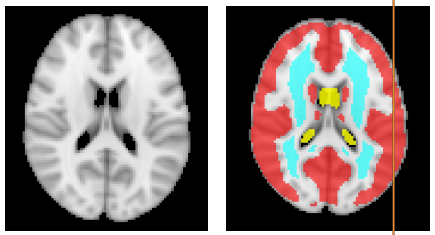
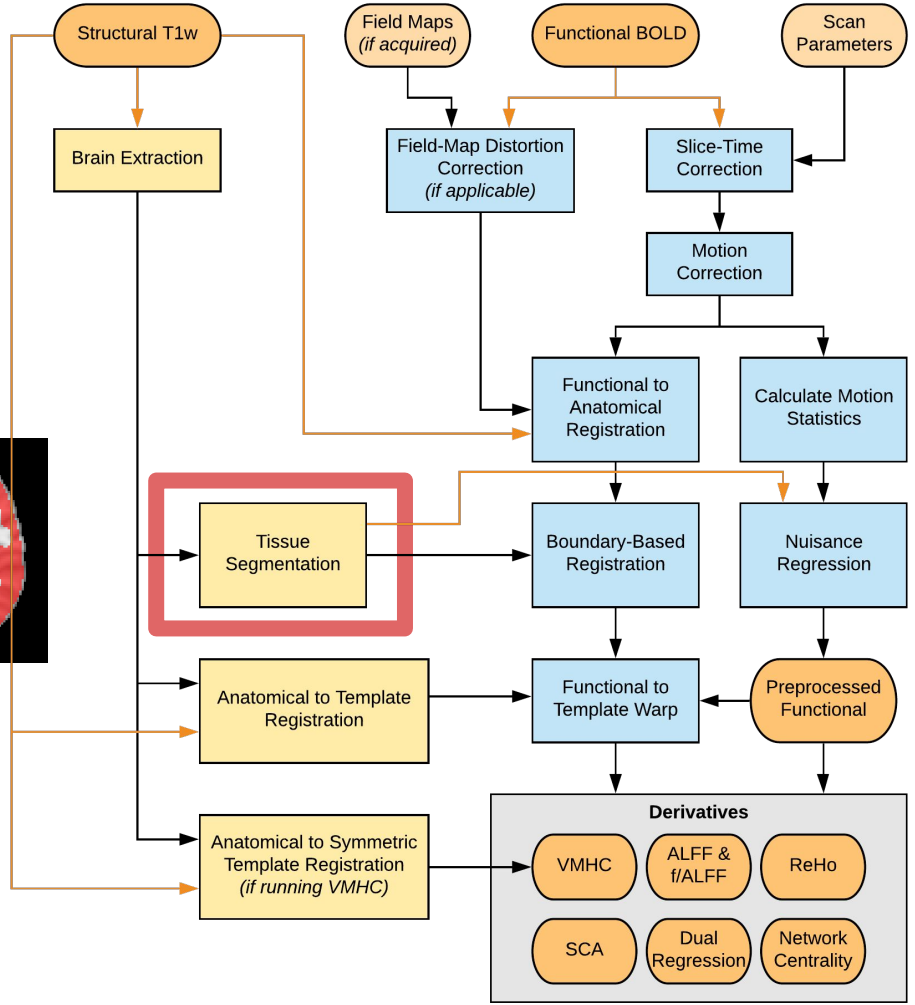


Image from https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/BET

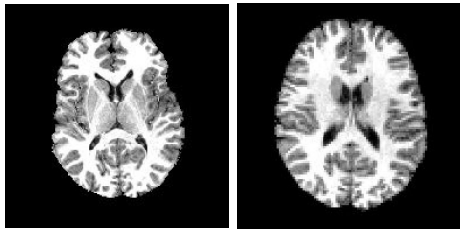


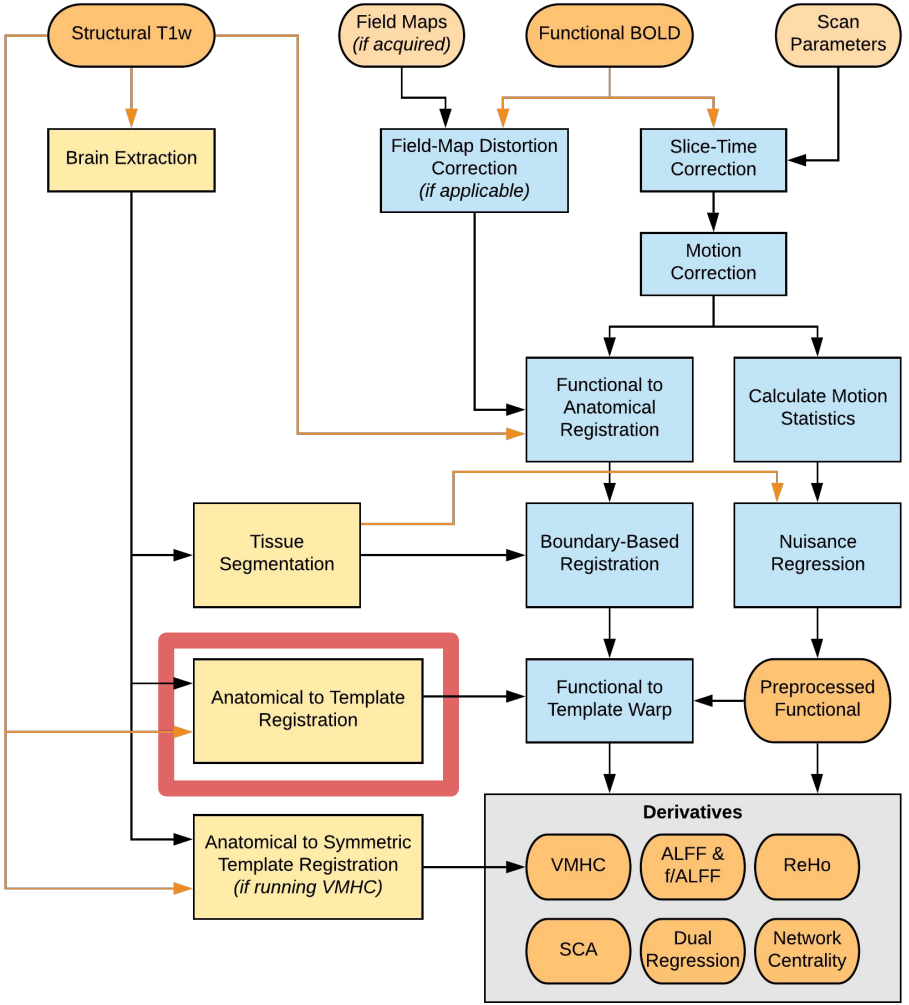
Anatomical Preprocessing: Tissue Segmentation



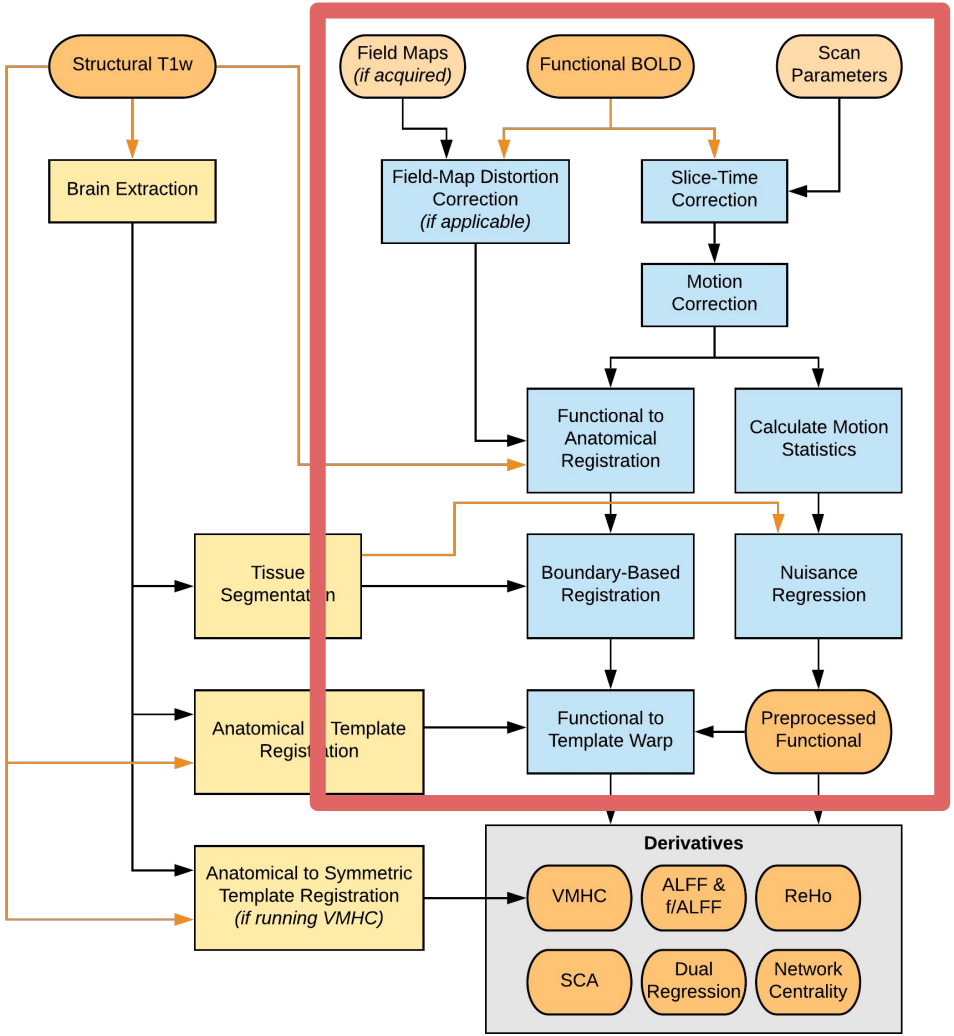


Anatomical Preprocessing: Anatomical Registration

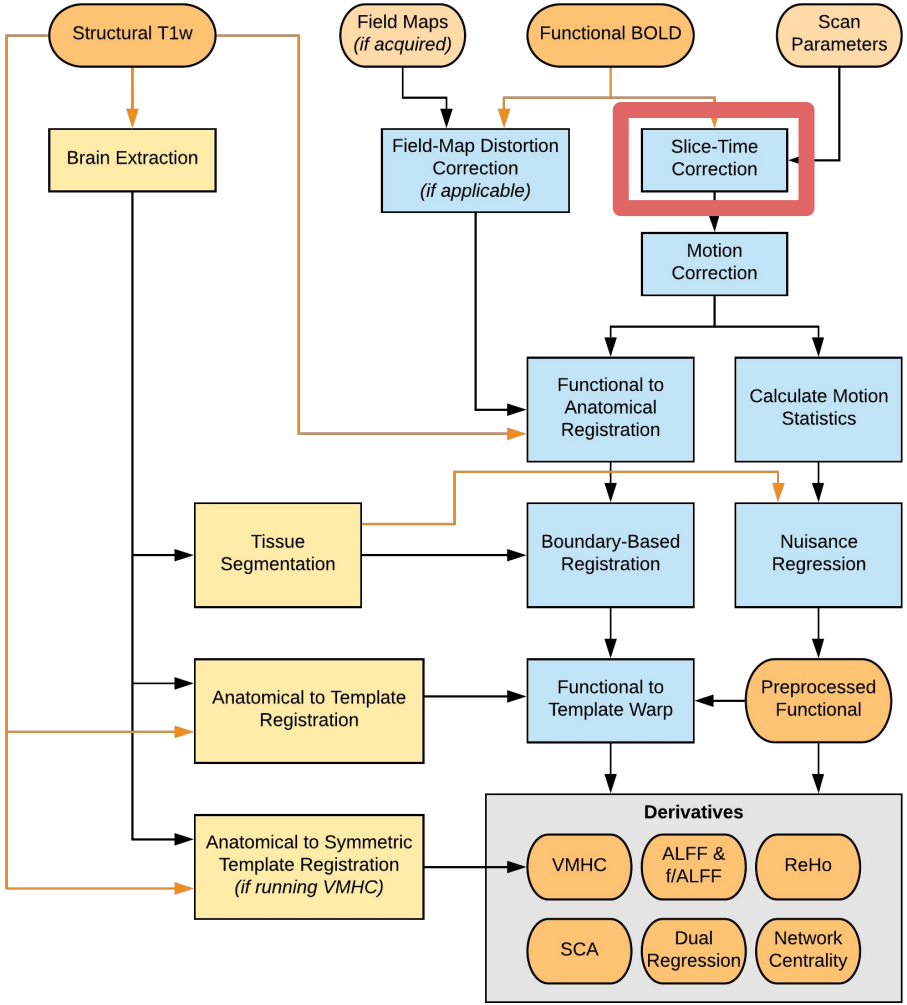


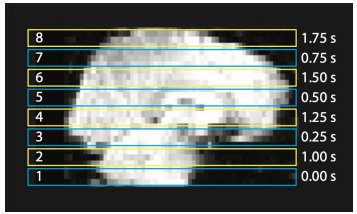


Functional Preprocessing

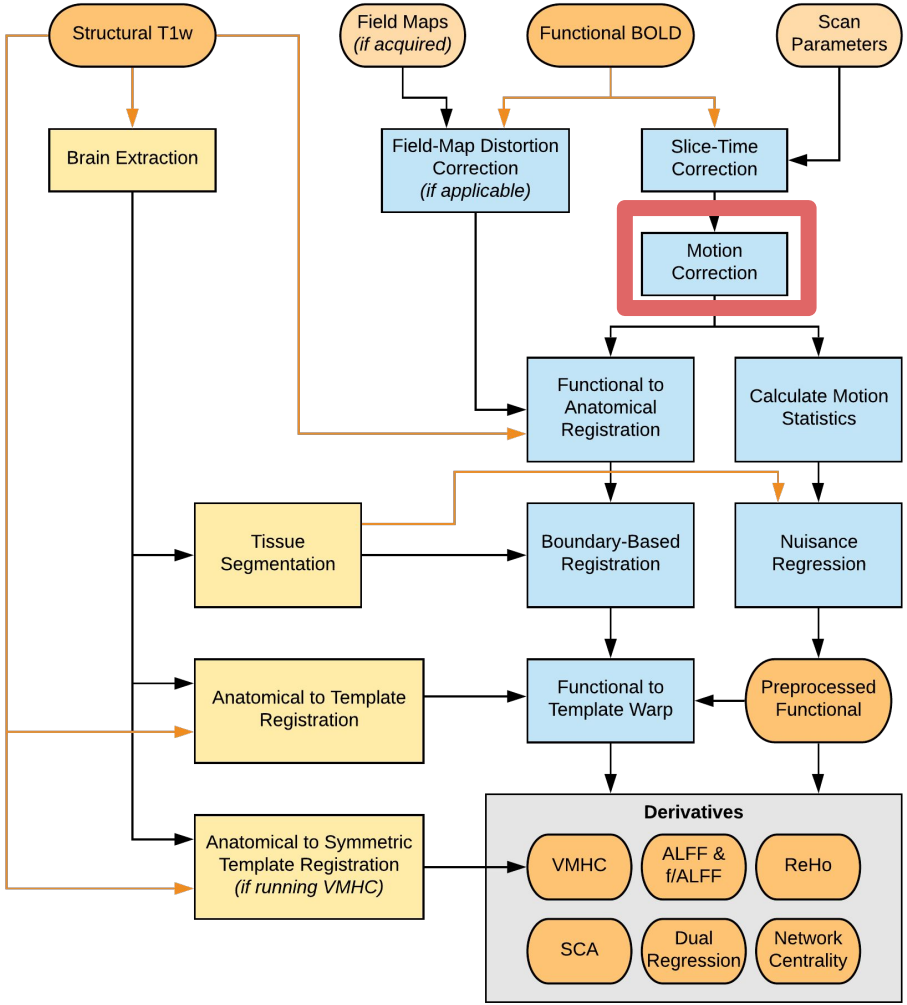


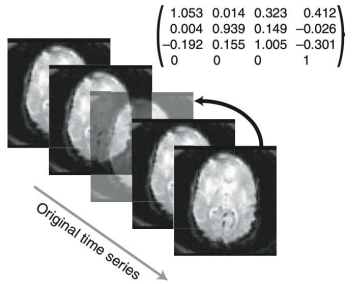
Functional Preprocessing: Slice-Time Correction



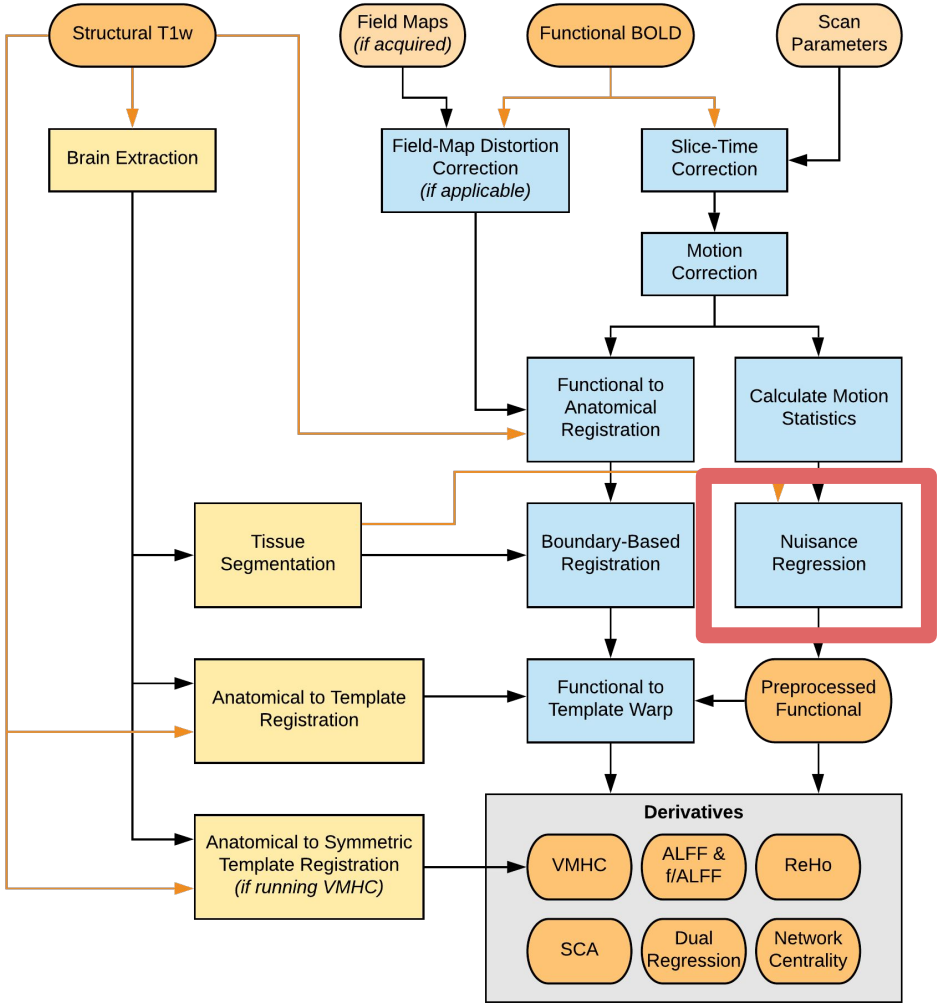


Functional Preprocessing: Motion Correction



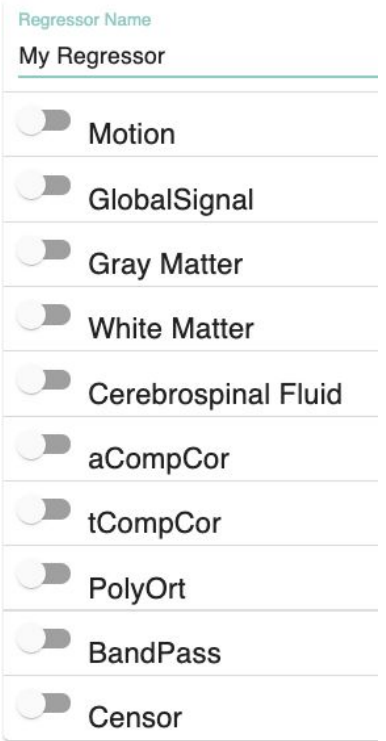


Functional Preprocessing: Nuisance Regression

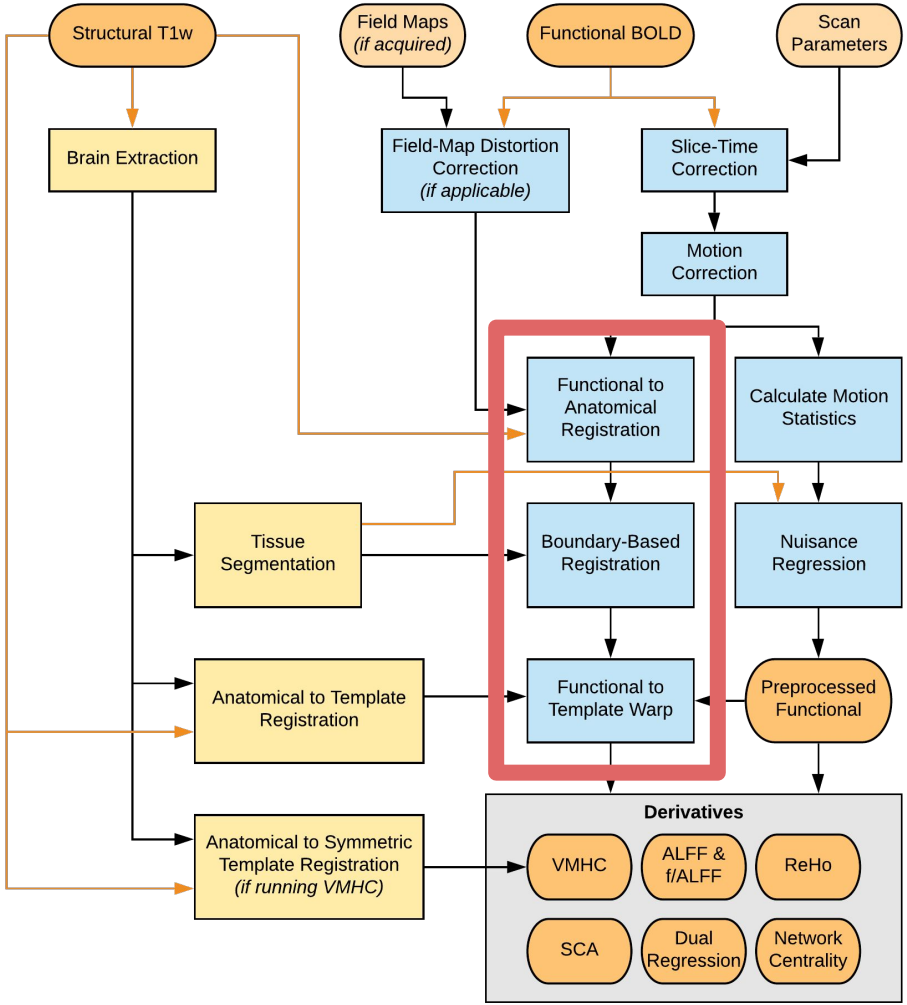


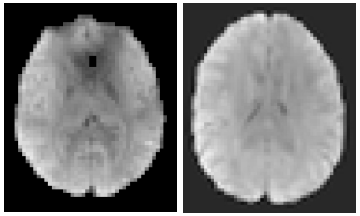
Functional Preprocessing: Nuisance Regression

- Motion
  - 6-parameter model
  - 24-parameter model Friston et al., 1996. Cited by 2789
- Global Signal Regression (GSR)
  - Fox et al., 2005. Cited by 7779
- WM and CSF regression
- aCompCor and tCompCor
  - Noise ROI component-based noise correction
  - Behzadi et al., 2007. Cited by 2633
- Polynomial Detrending
  - Removes linear or quadratic trend
- Temporal Filtering
  - Bandpass low-frequency
- Censor
  - Threshold FD (Framewise Displacement) and DVARS
  - Power et al., 2012. Cited by 5382
- ICA-AROMA Denoising
  - ICA-based Automatic Removal of Motion Artifacts
  - Pruim et al., 2015. Cited by 840

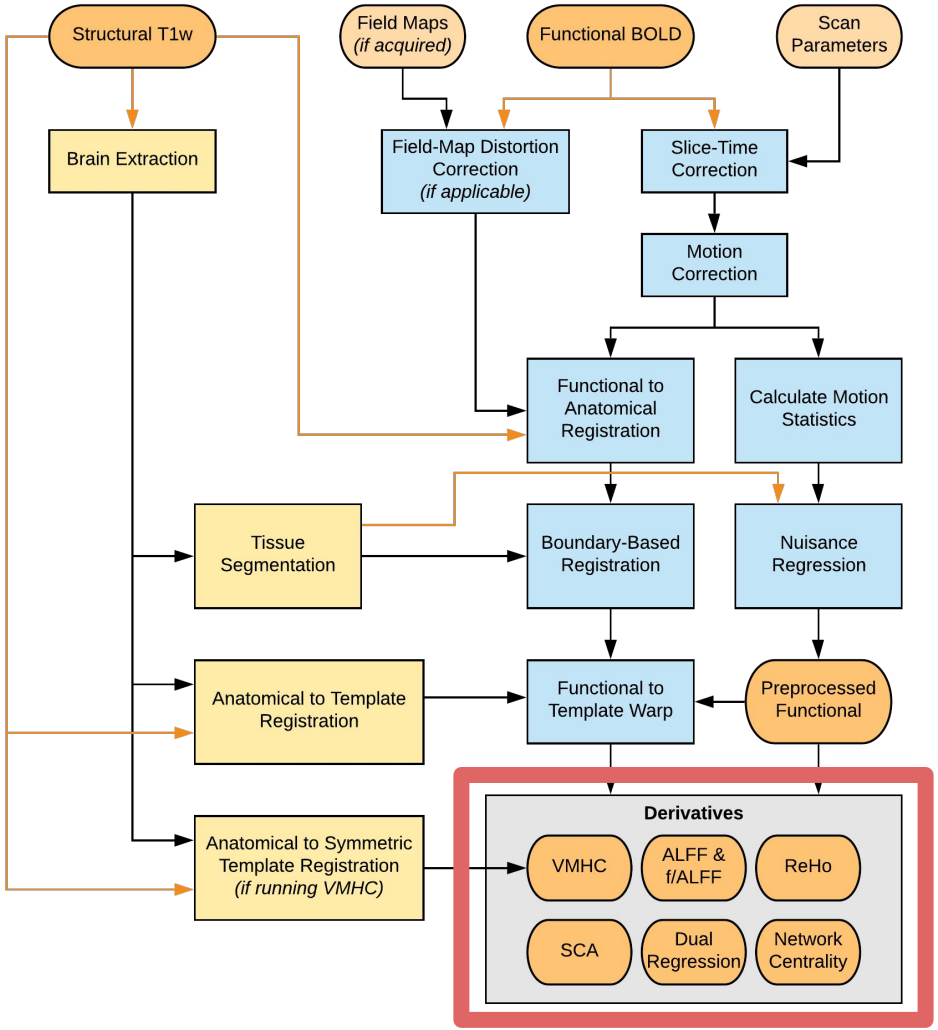


Functional Preprocessing: Registration

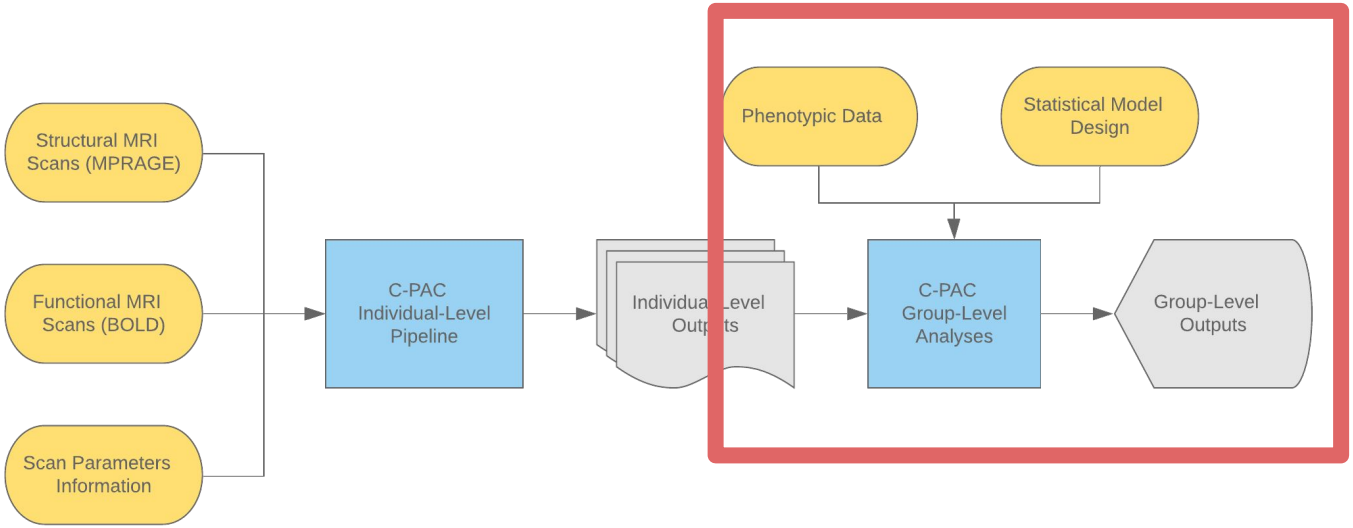




Functional Preprocessing: Derivatives



Group-Level Analyses

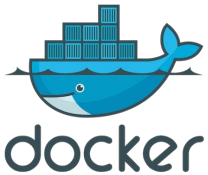


- FSL FEAT
- Non-Parametric Permutation Inference (FSL Randomise)

- What is C-PAC?
- Why is C-PAC?
- How does C-PAC work?
- How to run C-PAC in a container?
- Demo

How to run C-PAC?

>> docker run <dir mapping> <container image>




```
docker pull fcpindi/c-pac:latest
```

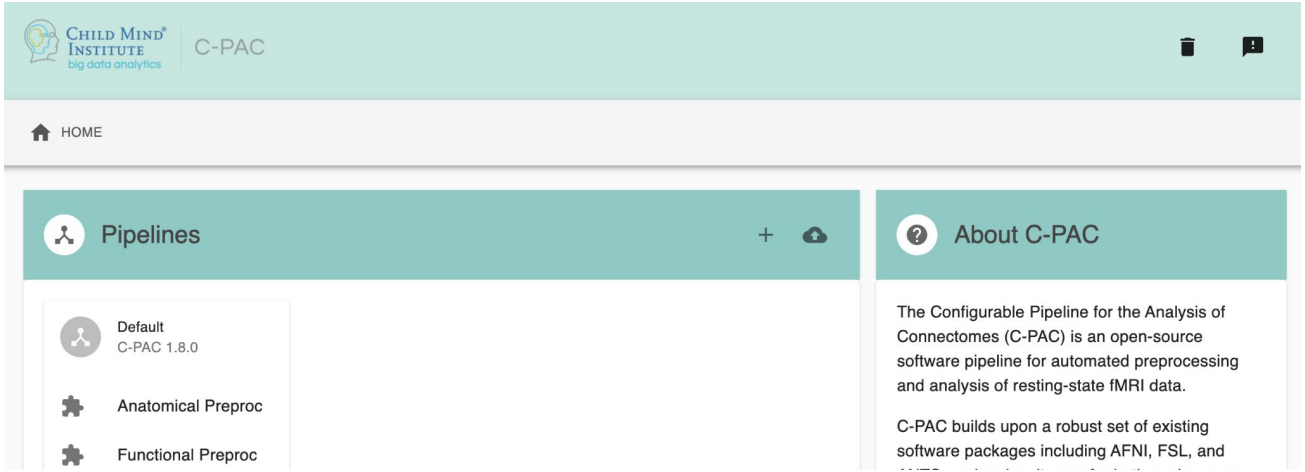
```
docker run -i --rm \
        -v /Users/You/local_bids_data:/bids_dataset \
        -v /Users/You/some_folder:/outputs \
        -v /tmp:/scratch \
        fcpindi/c-pac:latest /bids_dataset /outputs participant
```

>> singularity run <dir mapping> <container image>

```
singularity pull shub://FCP-INDI/C-PAC
```

```
singularity run \
        -B /Users/You/local_bids_data:/bids_dataset \
        -B /Users/You/some_folder:/outputs \
        -B /tmp:/scratch \
        FCP-INDI-C-PAC-master-latest.simg /bids_dataset /outputs participant
```

Pipeline Config



- GUI Editor
- Text-based YAML file Editor

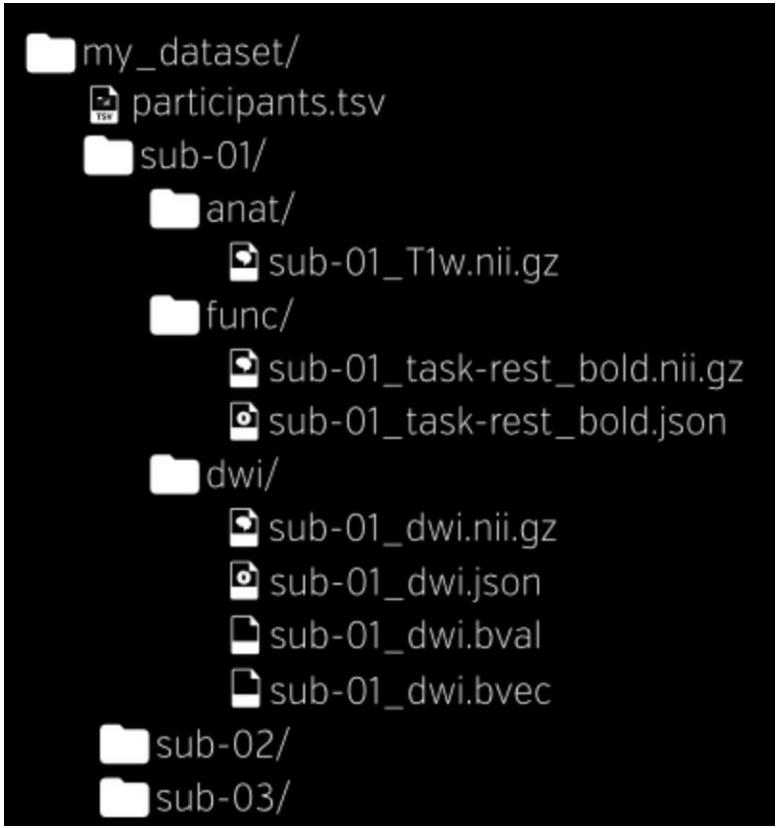
https://fcp-indi.github.io/C-PAC_GUI/versions/nightly/browser/#/

```
anatomical_preproc:
  run: On
  brain_extraction:
    run: On
    using:
      - 3dSkullStrip
```

```
docker run -i --rm \
       -v /Users/You/local_bids_data:/bids_dataset \
       -v /Users/You/some_folder:/outputs \
       -v /tmp:/scratch \
       -v /Users/You/Documents:/configs \
       -v /Users/You/resources:/resources \
       fcpindi/c-pac:latest /bids_dataset /outputs participant --pipeline_file /configs/pipeline_config.yml
```

Data Config

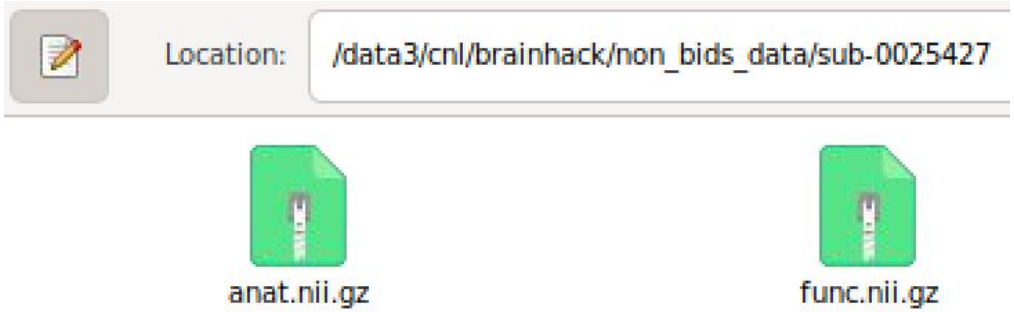
BIDS
BRAIN IMAGING DATA STRUCTURE



Gorgolewski, Krzysztof J., et al. "The brain imaging data structure, a format for organizing and describing outputs of neuroimaging experiments." *Scientific data* 3.1 (2016): 1-9.

Data Config

- Data Structure



- Non-BIDS Data Config

```
- anat: /non_bids_dataset/sub-0025427/anat.nii.gz
  func:
    rest_run-1:
      scan: /non_bids_dataset/sub-0025427/func.nii.gz
  site_id: site-none
  subject_id: sub-0025427
  unique_id: ses-1
```

```
docker run -i --rm \
       -v /Users/You/any_directory:/bids_dataset \
       -v /Users/You/some_folder:/outputs \
       -v /tmp:/scratch \
       -v /Users/You/Documents:/configs \
       fcpindi/c-pac:latest /bids_dataset /outputs participant --data_config_file /configs/data_config.yml
```

Optional arguments in C-PAC container

--pipeline_file
--data_config_file
--n_cpus

--mem_mb /--mem_gb
--save_working_dir
--anat_only
--participant_label

>> docker run fcpindi/c-pac:latest --help

```
docker run -i --rm \
       -v /Users/You/local_bids_data:/bids_dataset \
       -v /Users/You/some_folder:/outputs \
       -v /tmp:/scratch \
       -v /Users/You/Documents:/configs \
       -v /Users/You/resources:/resources \
       fcpindi/c-pac:latest /bids_dataset /outputs participant --pipeline_file /configs/pipeline_config.yml
```

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Demo Time!

https://github.com/XinhuiLi/OpenTutorials

For More Details

https://fcp-indi.github.io

C-PAC forum:
https://groups.google.com/forum/?utm_medium=email&utm_source=footer#!forum/cpax_forum

C-PAC GitHub issues:
https://github.com/FCP-INDI/C-PAC/issues