Toward an Open Science Ecosystem in Neuroimaging

Russ Poldrack
Stanford University

Transparency is essential for reproducibility

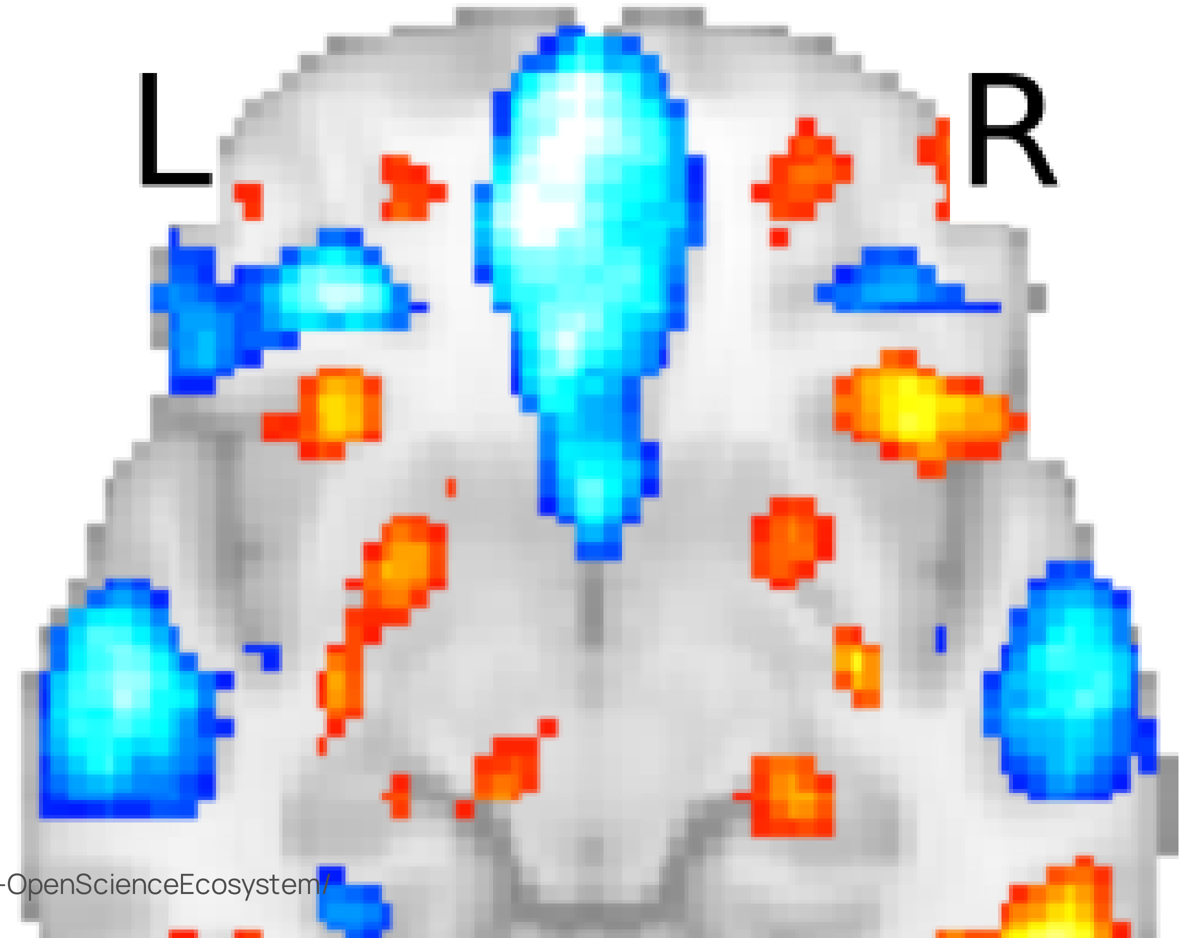
Analysis \ Data	Same	Different
Same	Reproducible	Replicable
Different	Robust	Generalisable

https://the-turing-way.netlify.app/reproducible-research/overview/overview-definitions.html "we can distill Claerbout's insight into a slogan:

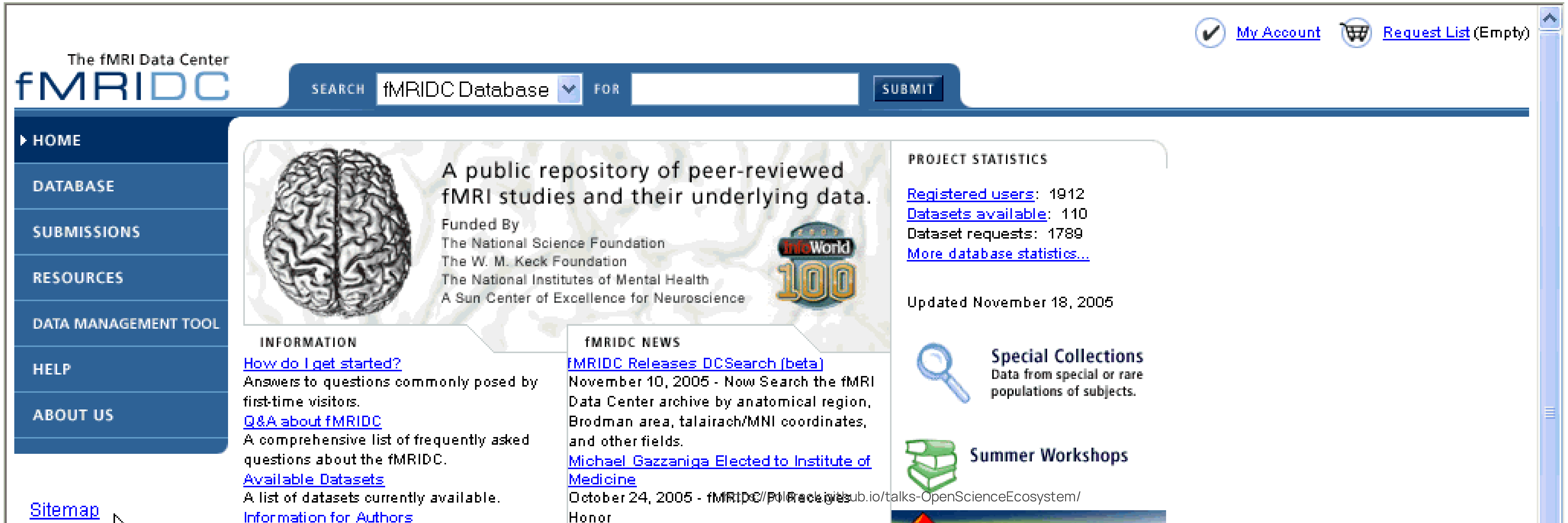
An article about computational science in a scientific publication is not the scholarship itself, it is merely advertising of the scholarship. The actual scholarship is the complete software development

Why neuroimaging is a best-case scenario for open science

- Magnetic resonance imaging (MRI) is the primary tool for studying human brain structure and function
- MRI data are digital end-to-end
  - From MRI scanner to automated analysis
  - Usually zero/few manual analysis steps



A false start for fMRI data sharing



A false start for fMRI data sharing

nature
neuroscience

A debate over fMRI data sharing

nature

3 August 2000 Volume 406 Issue no 6795

Whose scans are they, anyway?

This letter comes from a group of scientists who are publishing papers using fMRI to understand the links between brain and behavior. We are writing in reaction the recent announcement of the creation of the National fMRI Data Center (www.fmridc.org). In the letter announcing the creation of the center, it was also implied that leading journals in our field may require authors of all fMRI related papers accepted for publication to submit all experimental data pertaining to their paper to the Data Center. …
We are particularly concerned with any journal's

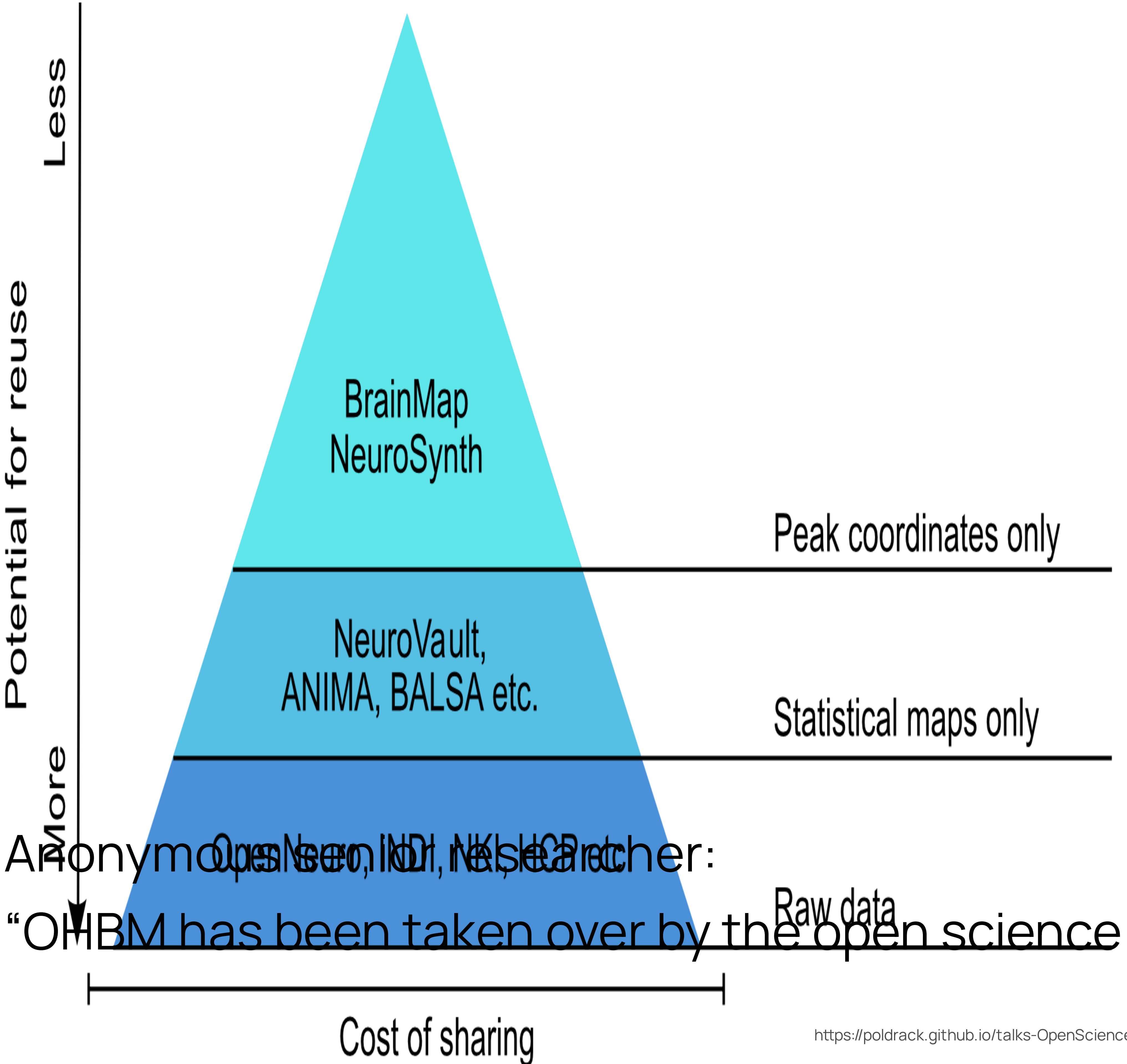
2010: The year data sharing broke in neuroimaging

Toward discovery science of human brain function

Bharat B. Biswal[a], Maarten Mennes[b], Xi-Nian Zuo[b], Suril Gohel[a], Clare Kelly[b], Steve M. Smith[c], Christian F. Beckmann[c], Jonathan S. Adelstein[b], Randy L. Buckner[d], Stan Colcombe[e], Anne-Marie Dogonowski[f], Monique Ernst[g], Damien Fair[h], Michelle Hampson[i], Matthew J. Hoptman[j], James S. Hyde[k], Vesa J. Kiviniemi[l], Rolf Kötter[m], Shi-Jiang Li[n], Ching-Po Lin[o], Mark J. Lowe[p], Clare Mackay[c], David J. Madden[q], Kristoffer H. Madsen[f], Daniel S. Margulies[r], Helen S. Mayberg[s], Katie McMahon[t], Christopher S. Monk[u], Stewart H. Mostofsky[v], Bonnie J. Nagel[w], James J. Pekar[x], Scott J. Peltier[y], Steven E. Petersen[z], Valentin Riedl[aa], Serge A. R. B. Rombouts[bb], Bart Rypma[cc], Bradley L. Schlaggar[dd], Sein Schmidt[ee], Rachael D. Seidler[ff,u], Greg J. Siegle[gg], Christian Sorg[hh], Gao-Jun Teng[ii], Juha Veijola[jj], Arno Villringer[ee,kk], Martin Walter[ll], Lihong Wang[q], Xu-Chu Weng[mm], Susan Whitfield-Gabrieli[nn], Peter Williamson[oo], Christian Windischberger[pp], Yu-Feng Zang[qq], Hong-Ying Zhang[ii], F. Xavier Castellanos[b,j], and Michael P. Milham[b,1]

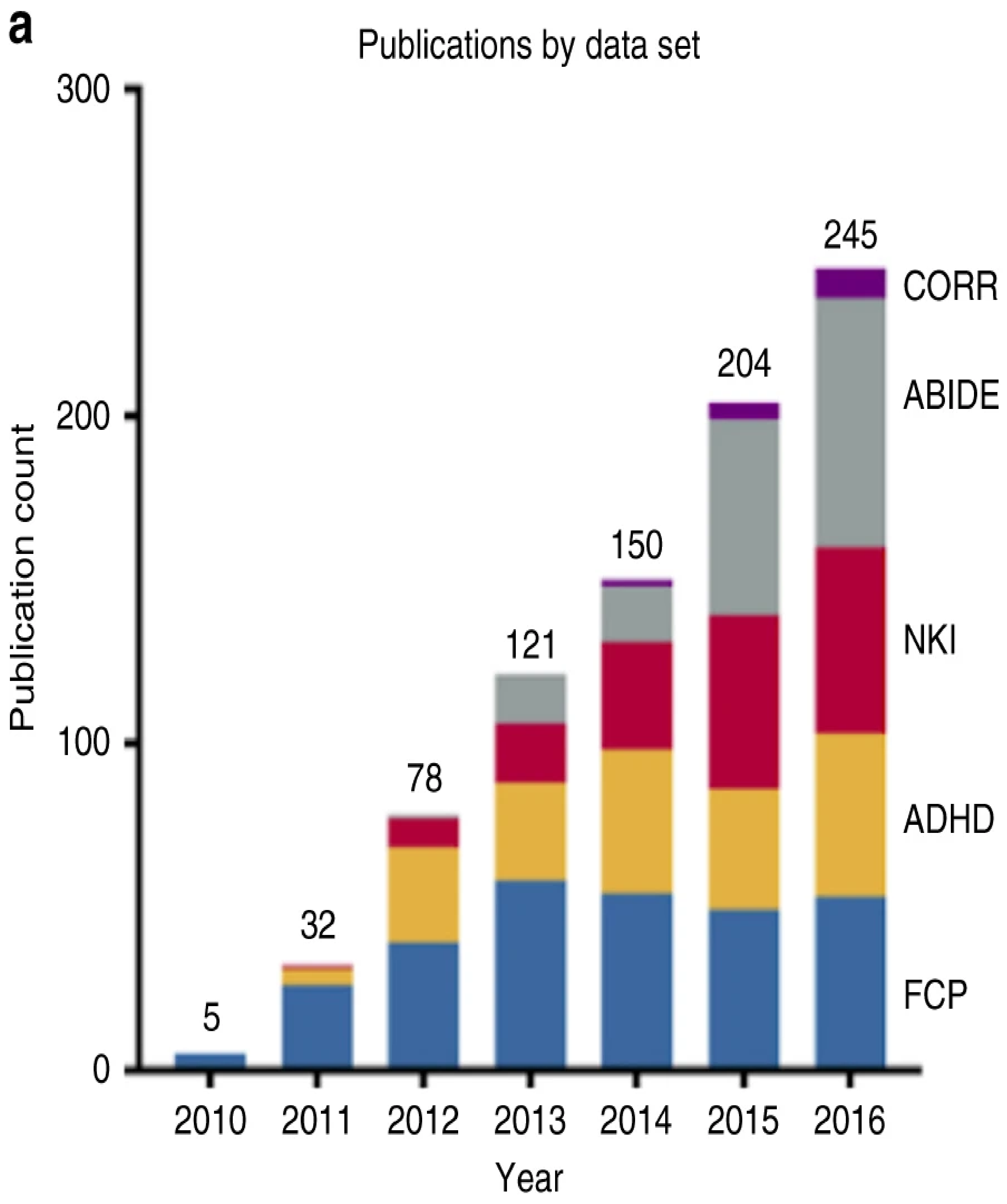
4734–4739 | PNAS | March 9, 2010 | vol. 107 | no. 10

Data sharing is becoming the norm in neuroimaging



Anonymous senior researcher:

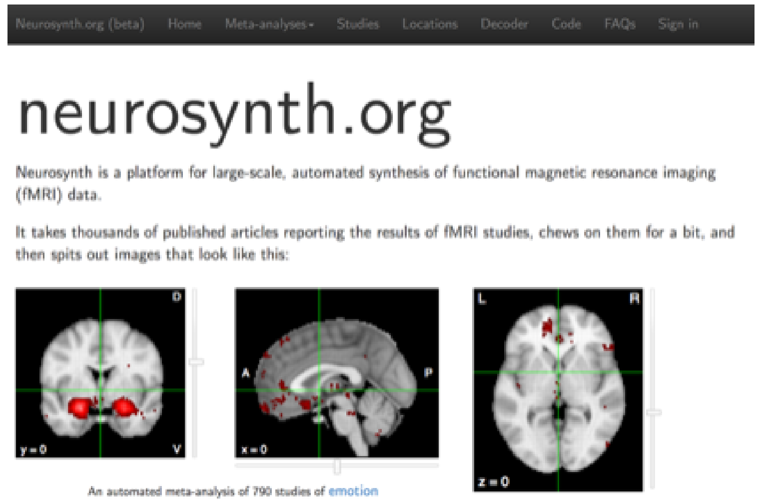
"OHBM has been taken over by the open science zealots!"



Milham et al., *Nature Communications*, 2018

An open ecosystem for retrospective data sharing

Breadth



NEUROVAULT

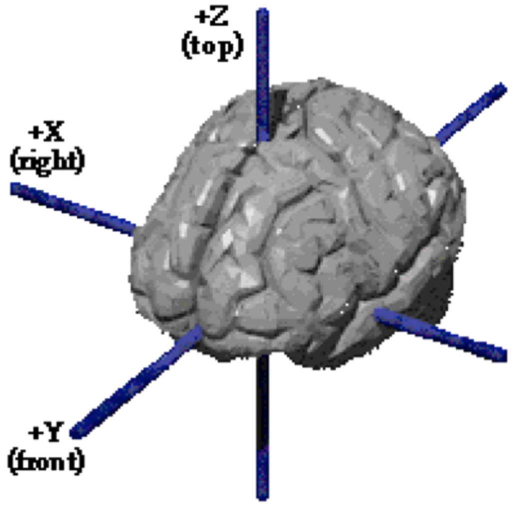
- Neurosynth.org: Open database of published neuroimaging coordinates
- Neurovault.org: Open archive for neuroimaging results
- OpenNeuro.org: Open

Maximally open sharing

- Data shared under maximally permissive data use agreements:
  - Neurosynth: Open Data Commons Open Database License v1.0
  - Neurovault: CC0
  - OpenNeuro: CC0
- All data available programmatically via web API

- CC0 enables scientists, educators, artists and other creators and owners of copyright- or database-protected content to waive those interests in their works and thereby place them as

Neurosynth: Sharing activation coordinates



- Brain activity is reported in a (somewhat) standardized coordinate system

Table 1
Regions that showed a condition × time interaction in the ANOVA analysis

No.	Region	Hemisphere	BA	*x*	*y*	*z*	mm^3
1	Middle/superior temporal gyrus	L	21/22/37	−52	−54	9	13257
2	Inferior frontal gyrus	L	45/46/9	−49	26	6	2781
3	Posterior cerebellum	L		−19	−79	−38	2214
4	Dorsomedial PFC	L	9/8	−11	42	47	3051
5	Left anterior PFC	L	10	−37	49	15	2025
6	Inferior parietal cortex	L	40/7	−42	−58	47	3132
7	Dorsal premotor cortex	L	6	−43	0	50	1485
8	Lingual gyrus	L	17	−10	−95	−2	378
9	Middle /superior temporal gyrus	R	21/22/37	52	−40	5	16470
10	Inferior frontal gyrus	R	45/46	51	28	6	2241
11	Posterior cerebellum	R		23	−78	−34	2808
12	Dorsomedial PFC	R	9	5	53	29	405

Creating meta-analytic maps

- Automated Coordinate Extraction
  - Automatically extracts activation tables from fMRI papers for 17 journals
  - Current database has 14,371 papers (with full text)
  - 84% sensitivity, 97% specificity against manual database (SumsDB)
- Meta-analytic maps created for each

X	Y	Z
12	57	-6
33	21	15
24	-6	51
28	10	18

↓

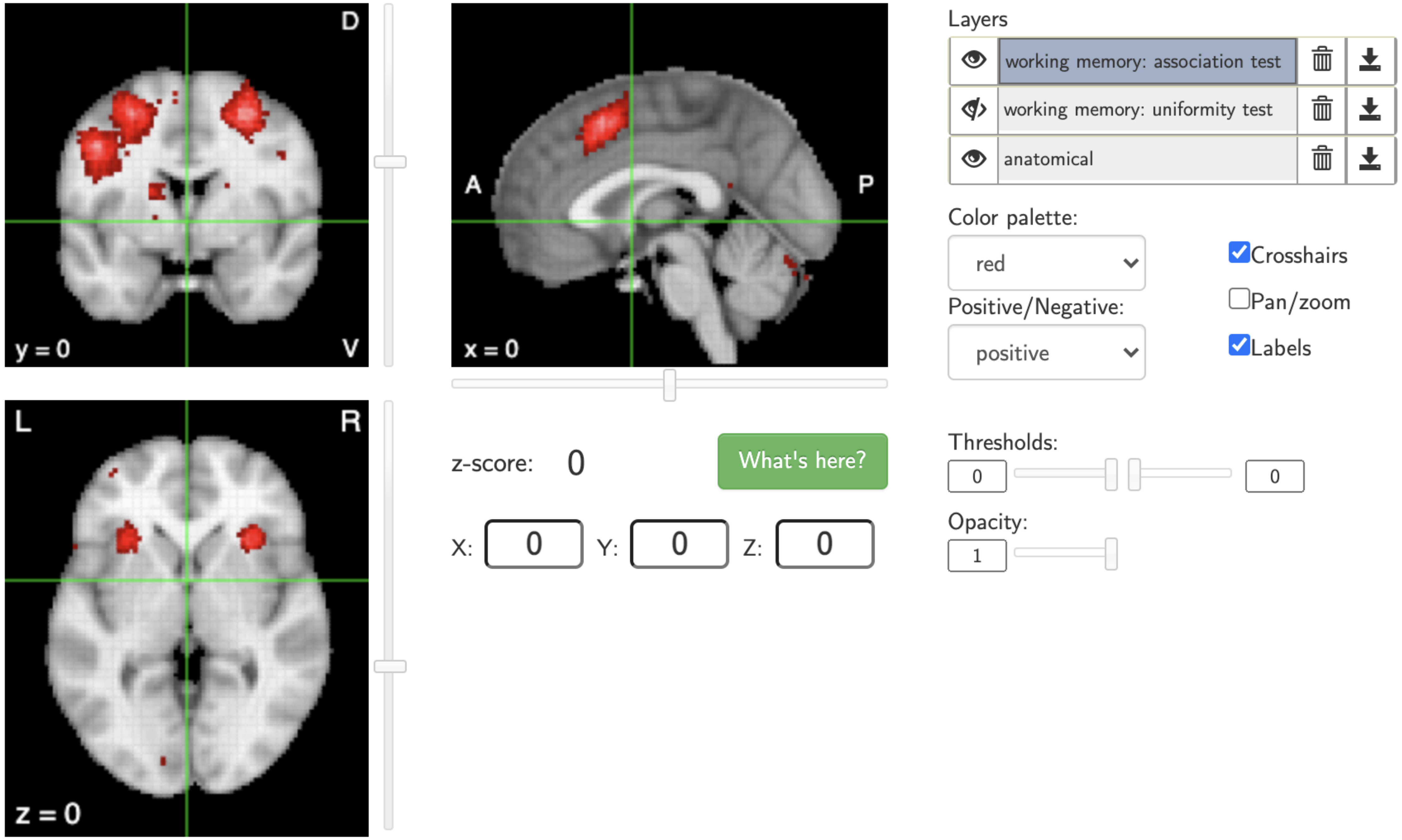
Yarkoni et al. 2011, *Nature Methods*

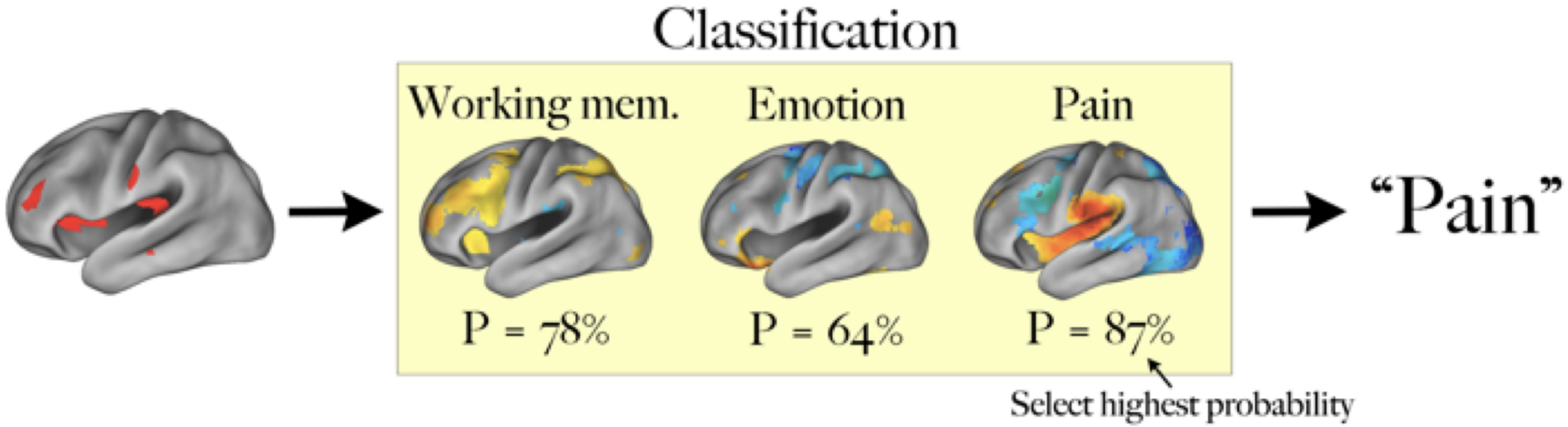
working memory

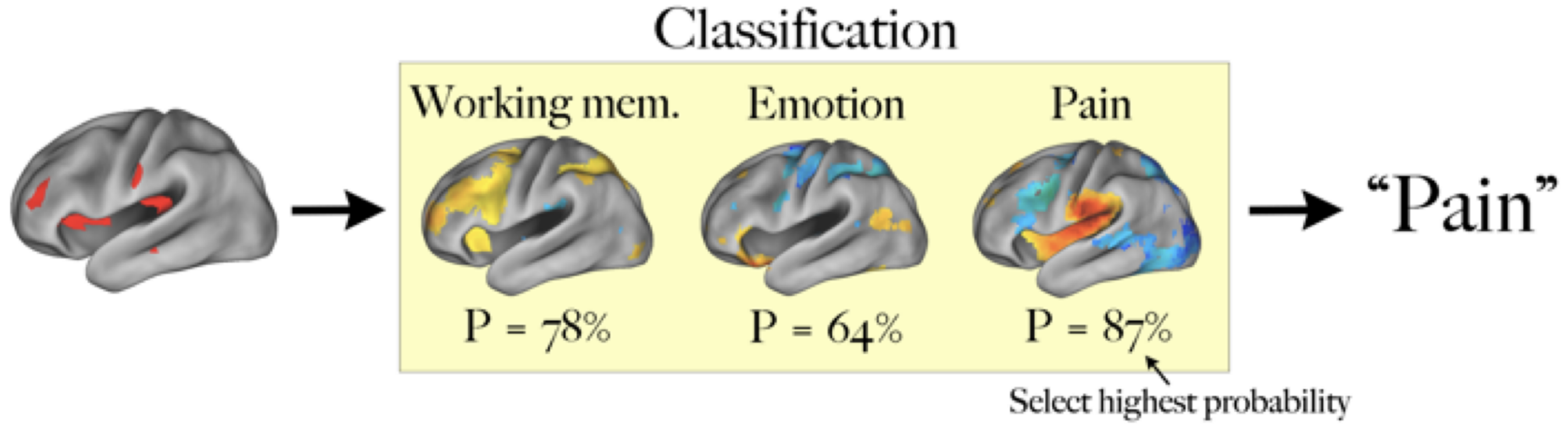
Search for another term:

An automated meta-analysis of 1091 studies

Maps Studies FAQs




Classification
Working mem.
Emotion
Pain
P = 78%
P = 64%
P = 87%
Select highest probability
"Pain"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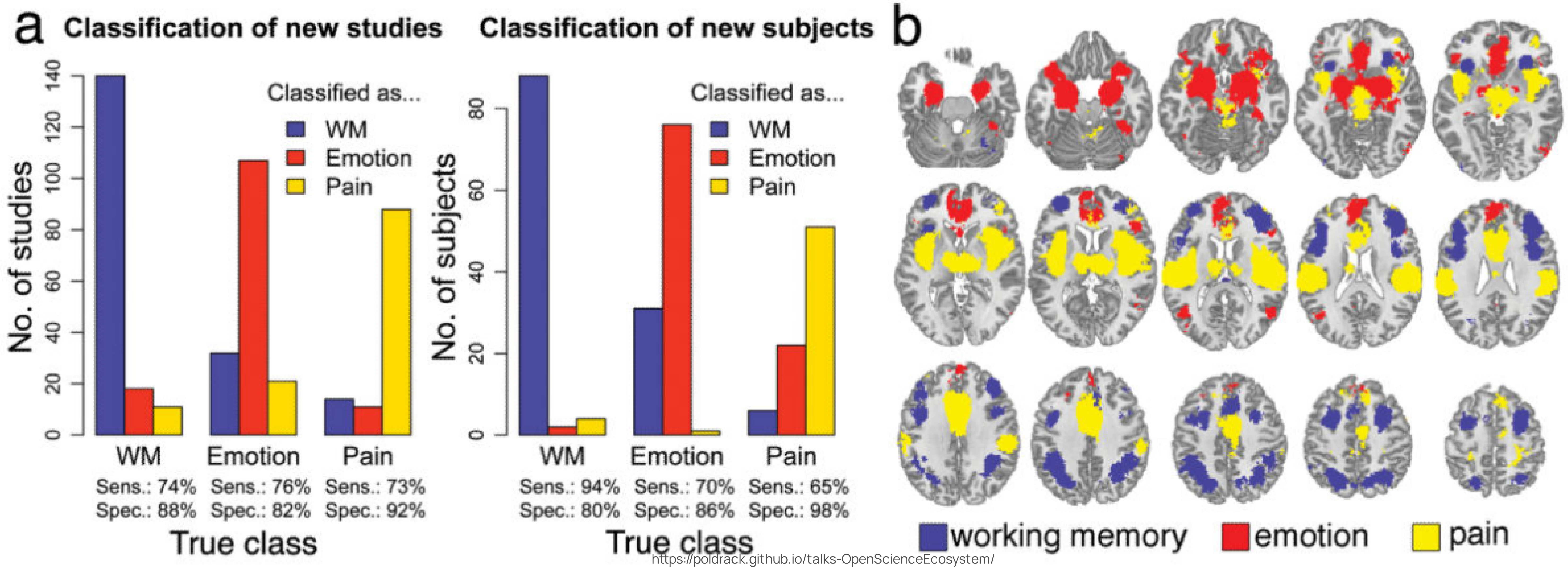
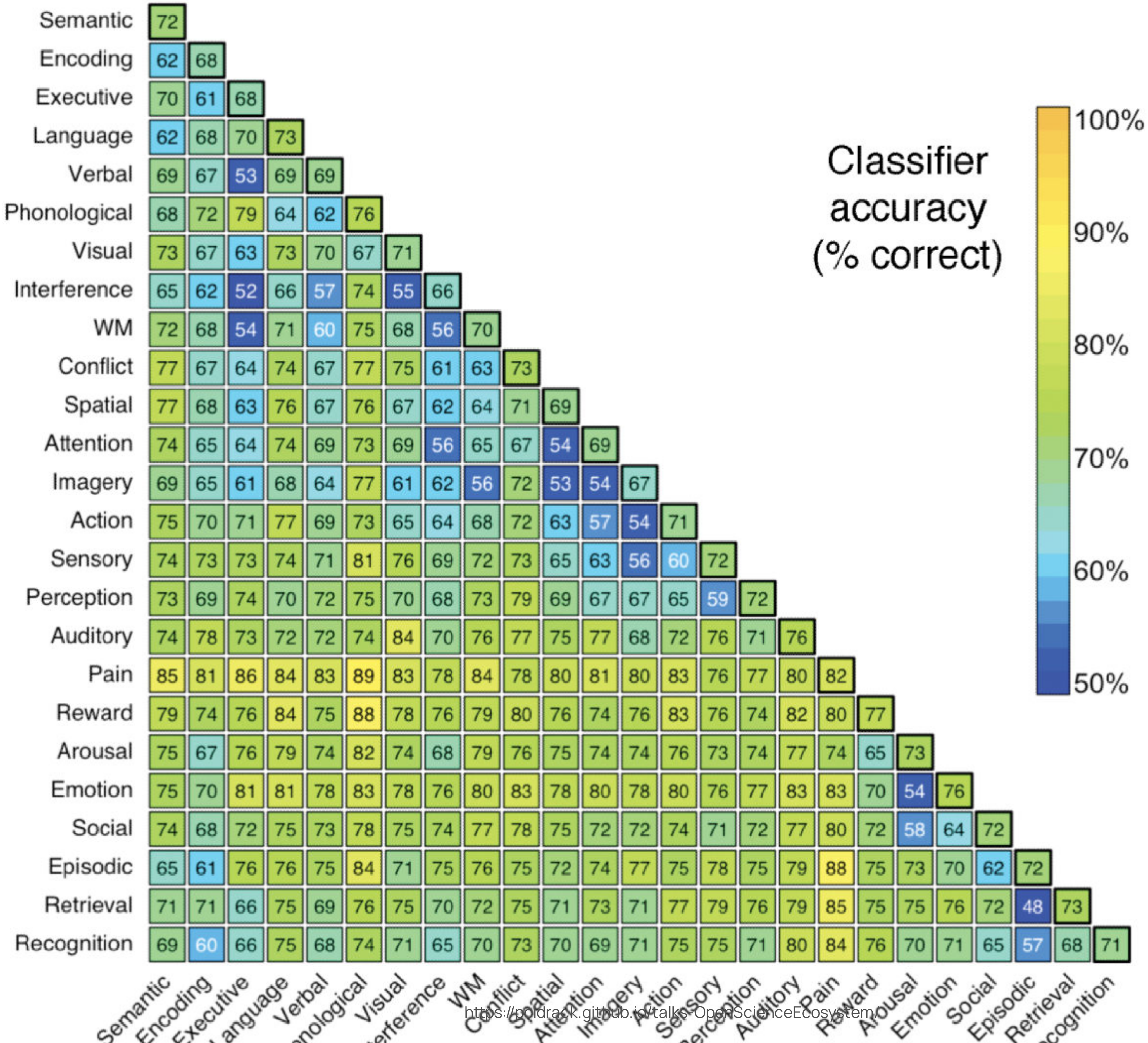

a
Classification of new studies
Classification of new subjects
b
Classified as...
WM
Emotion
Pain
No. of studies
0
20
40
60
80
100
120
140
No. of subjects
0
20
40
60
80
WM
Emotion
Pain
Sens.: 74%
Spec.: 88%
Sens.: 76%
Spec.: 82%
Sens.: 73%
Spec.: 92%
Sens.: 94%
Spec.: 80%
Sens.: 70%
Spec.: 86%
Sens.: 65%
Spec.: 98%
True class
True class
working memory
emotion
pain

Decoding brain activity patterns using Neurosynth

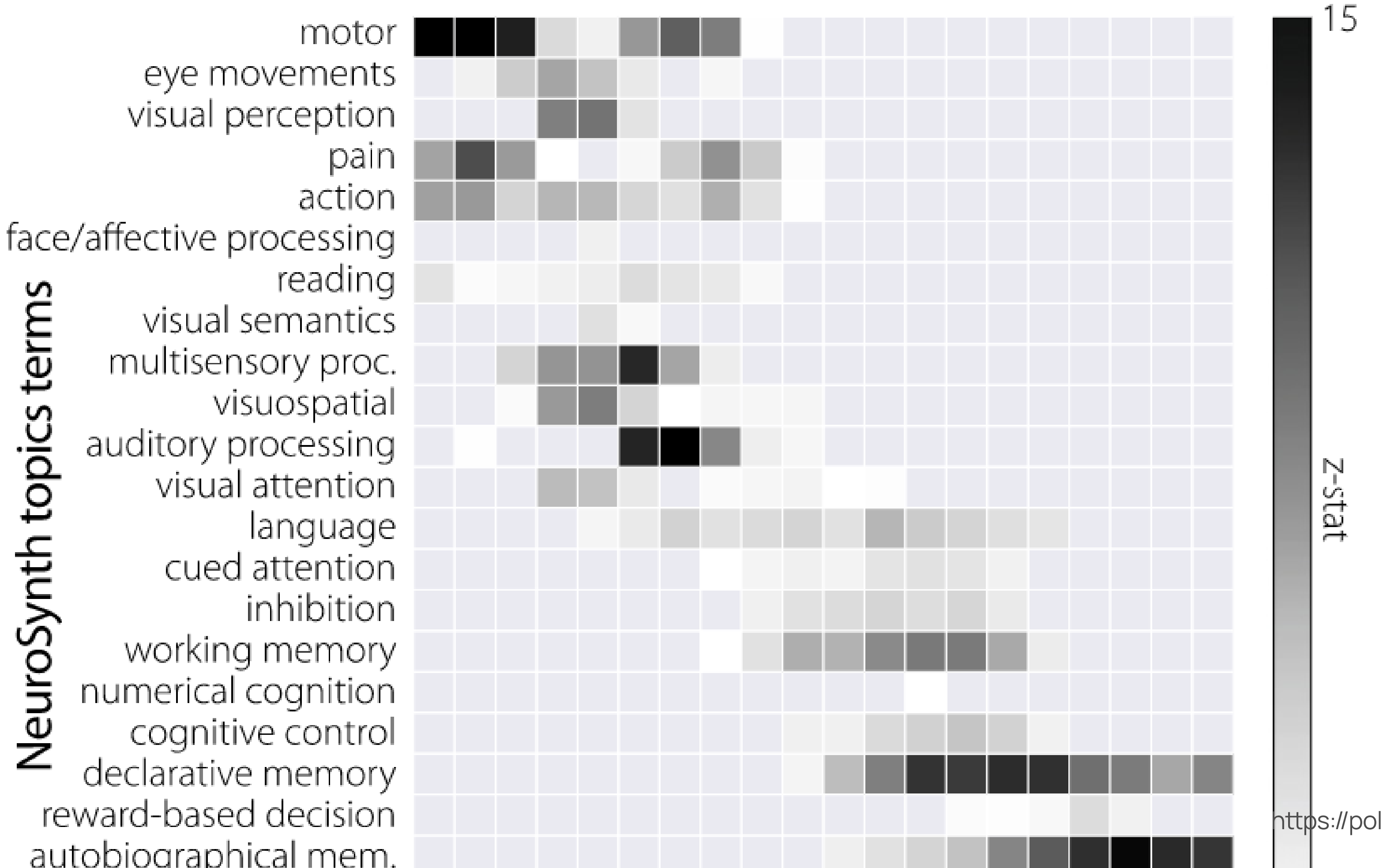


Example of Neurosynth usage

Situating the default-mode network along a principal gradient of macroscale cortical organization

Daniel S. Margulies[a,1], Satrajit S. Ghosh[b,c], Alexandros Goulas[d], Marcel Falkiewicz[a], Julia M. Huntenburg[a,e], Georg Langs[f,g], Gleb Bezgin[h], Simon B. Eickhoff[i,j], F. Xavier Castellanos[k,l], Michael Petrides[m], Elizabeth Jefferies[n,o], and Jonathan Smallwood[n,o]

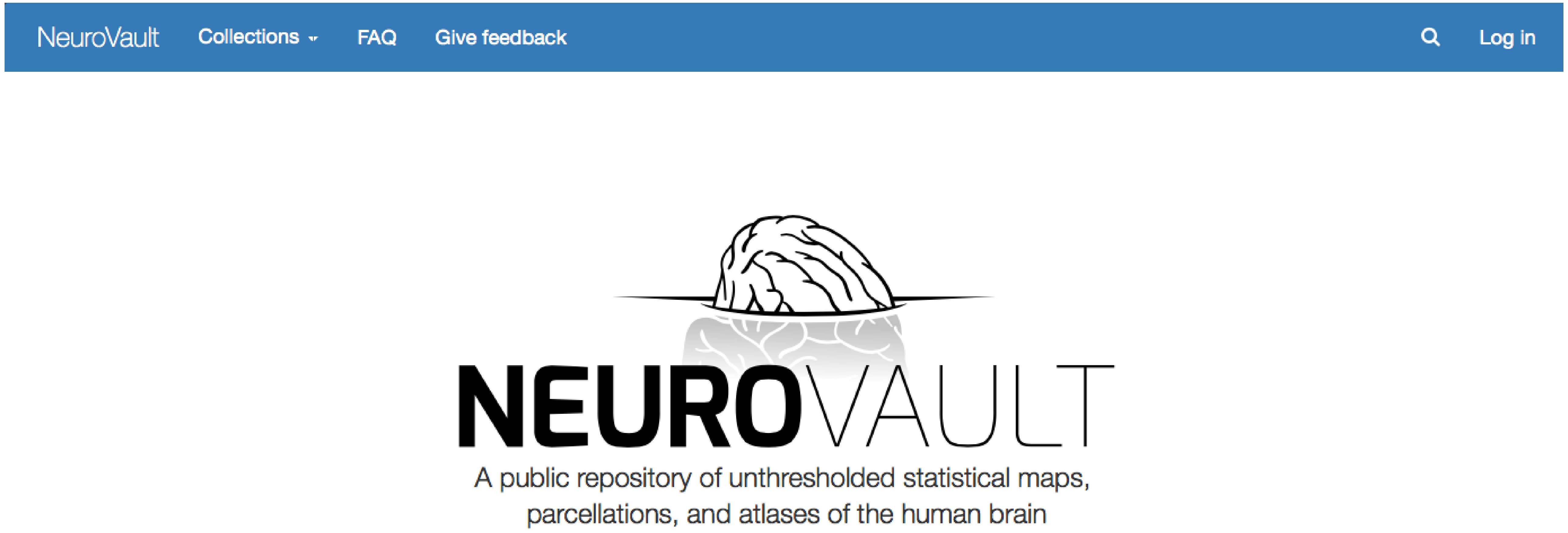
12574–12579 | PNAS | November 1, 2016 | vol. 113 | no. 44



- Identified gradients of functional organization across the cortex
- Used Neurosynth to identify the most common terms associated with each gradient

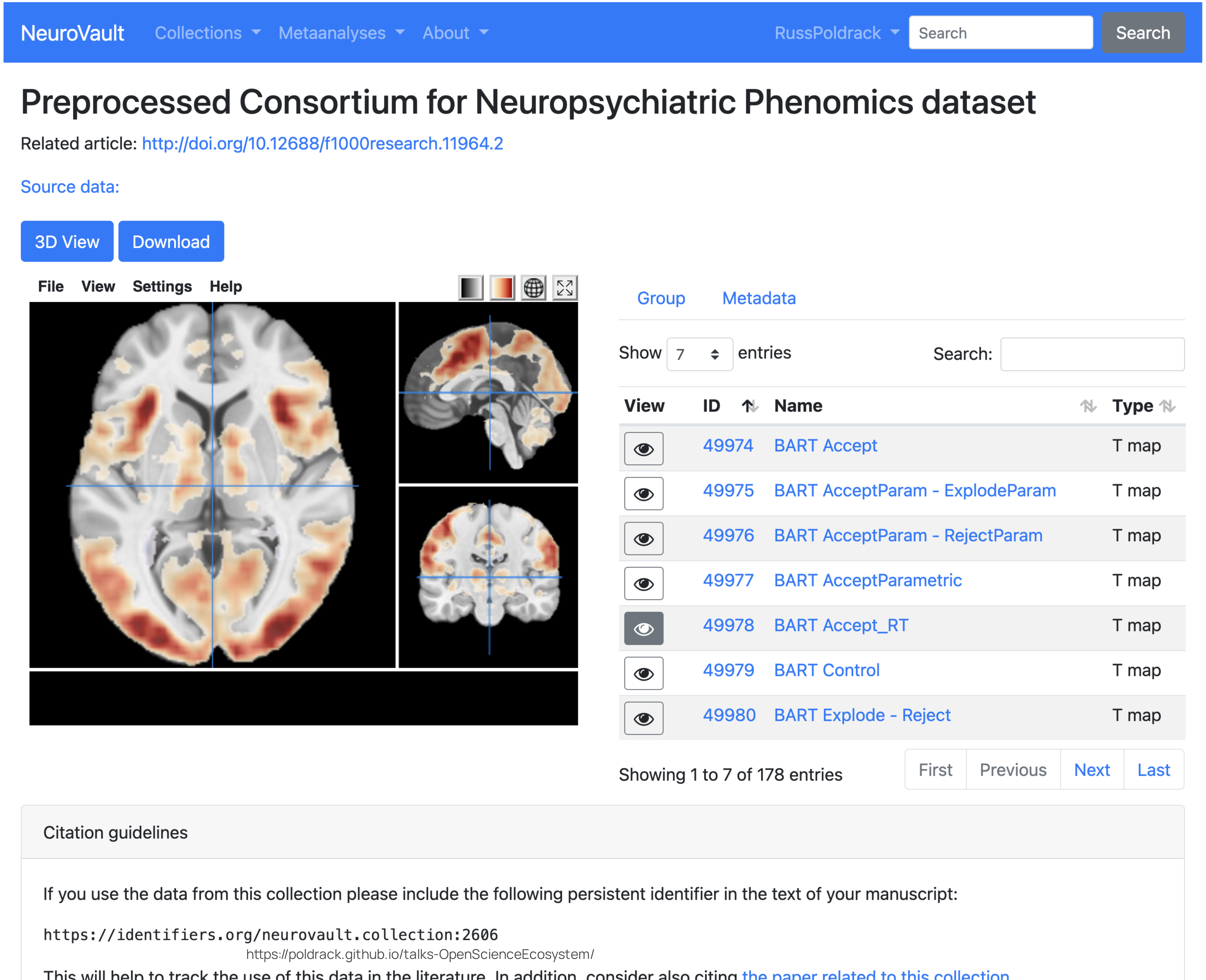
Neurovault: Sharing neuroimaging results

- The results of most neuroimaging studies are images with statistical estimates at each voxel
- Neurovault.org is an open archive for these results

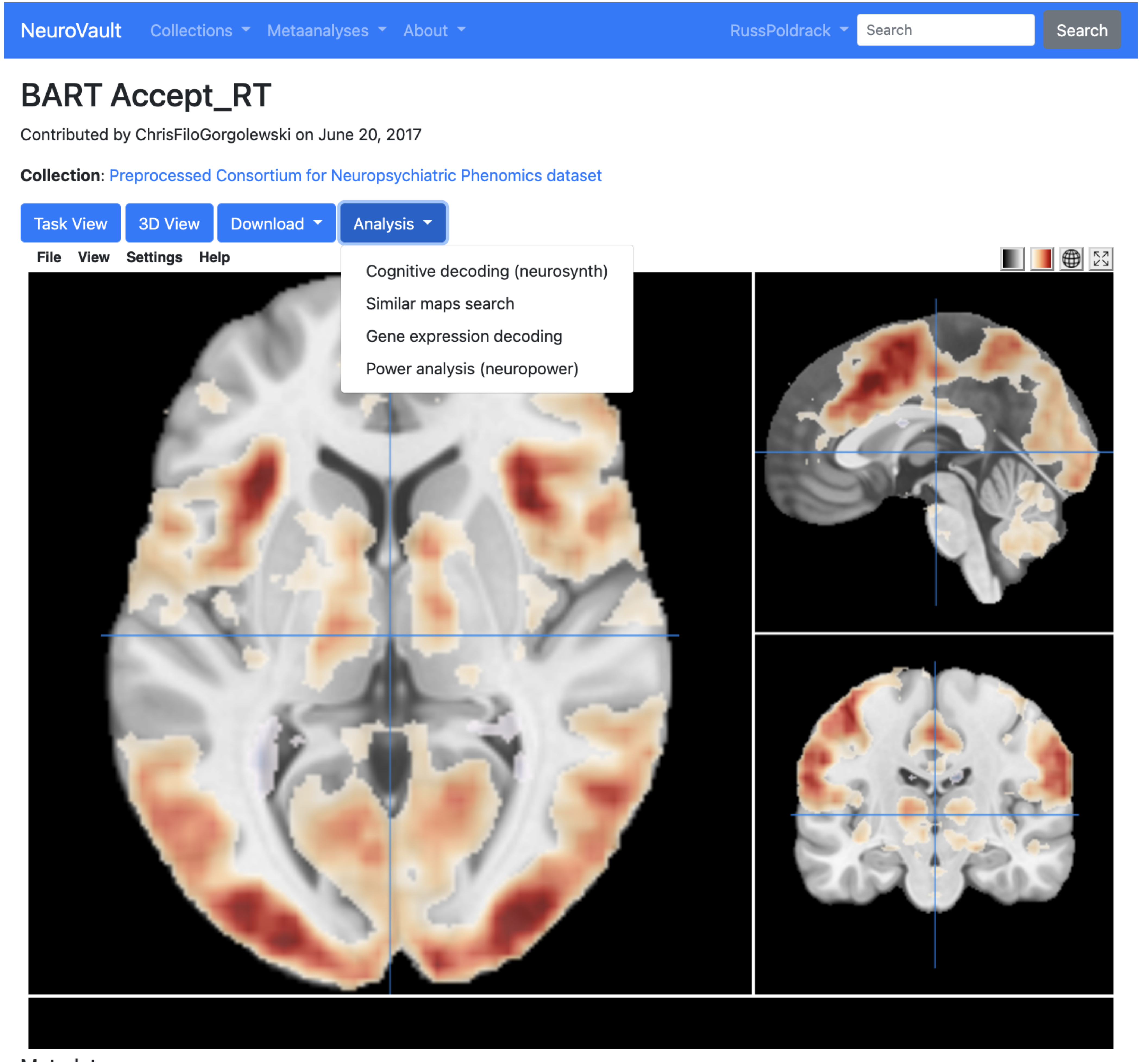


Gorgolewski et al., 2015, *Frontiers in Neuroinformatics*

- **Collections**
  - A set of images (such as all images from a particular paper) can be uploaded as a collection
  - Each collection receives a persistent identifier



- **Image browser**
  - Individual images can be browsed and downloaded
  - A number of analysis tools can also be applied
  - Each image also receives a persistent identifier

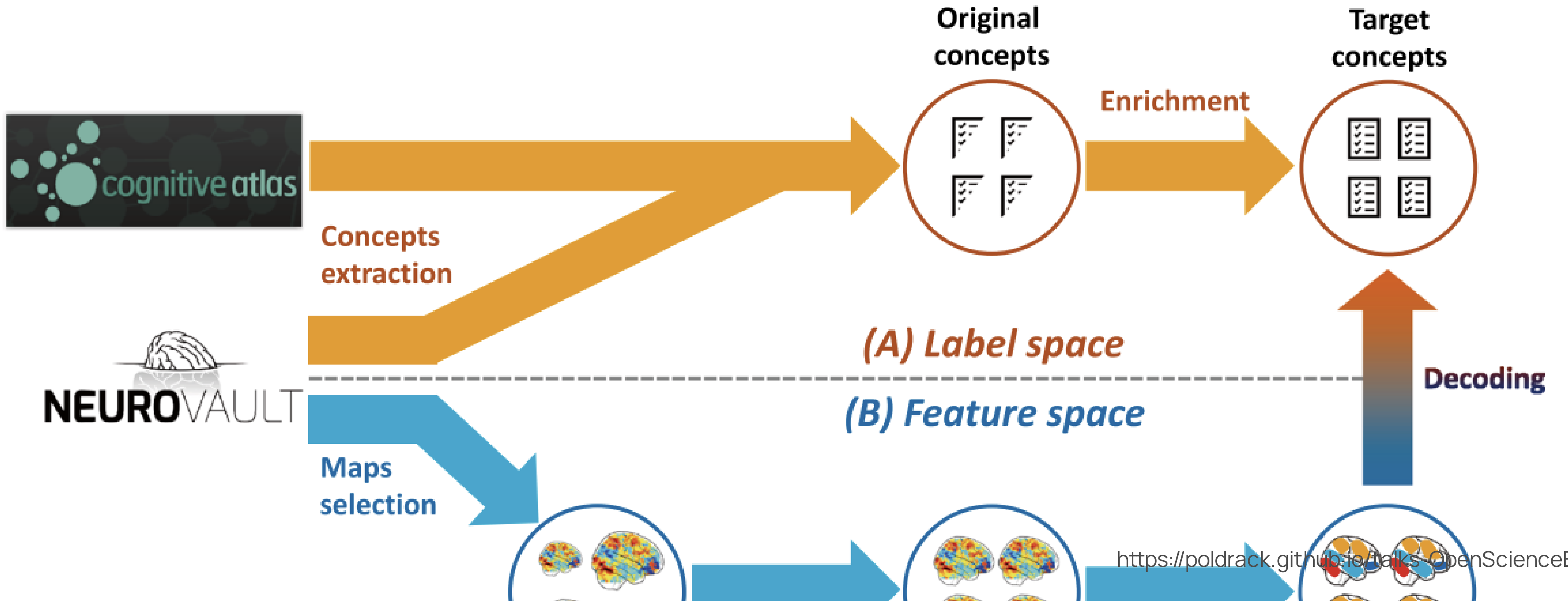


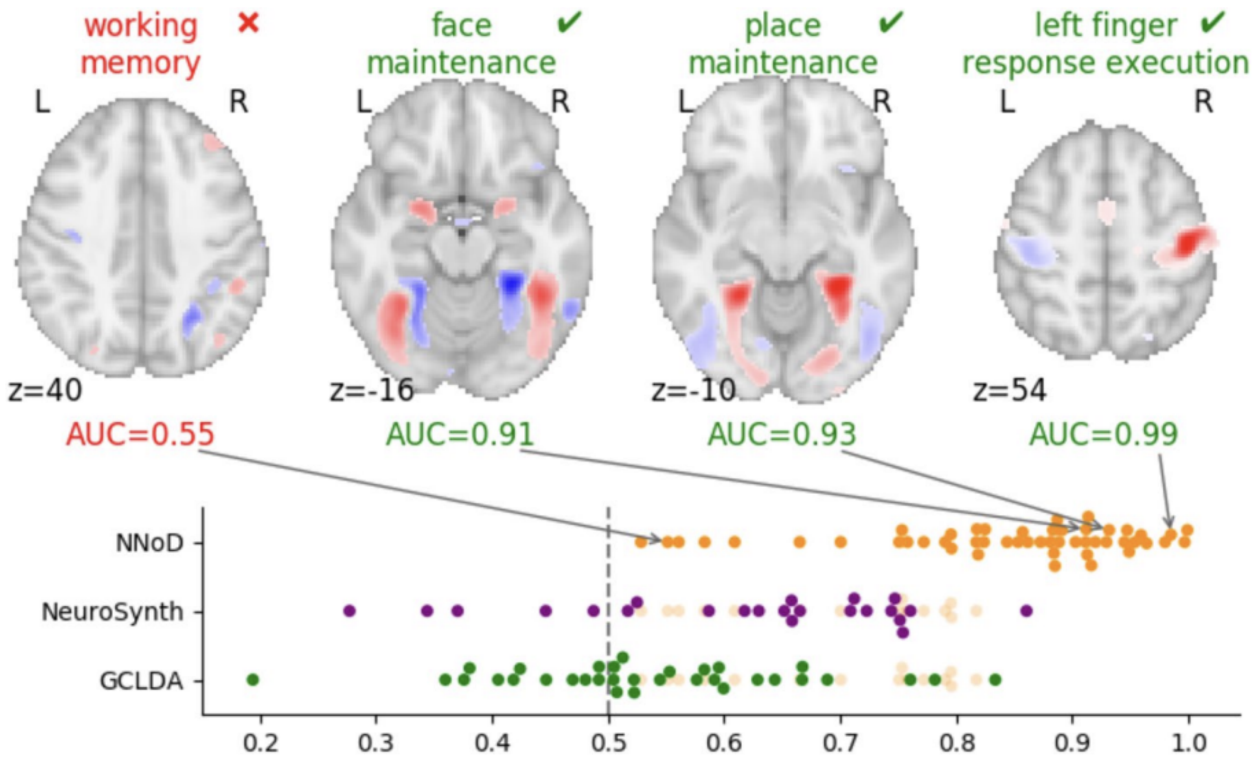
Example of Neurovault usage

Comprehensive decoding mental processes from Web repositories of functional brain images

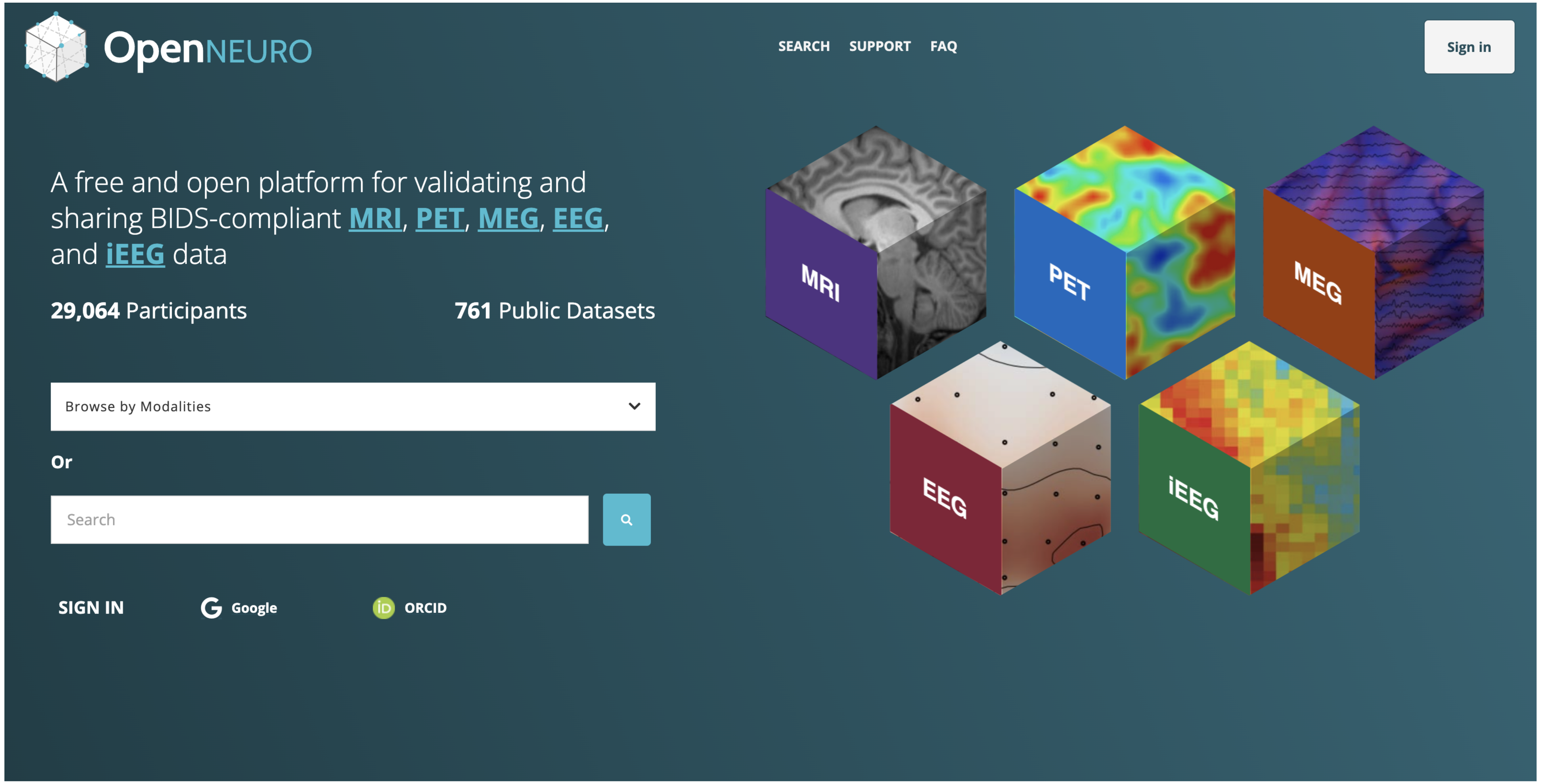
Romuald Menuet[5,6], Raphael Meudec[1,2,3,6], Jérôme Dockès[4], Gael Varoquaux[1,2,3] & Bertrand Thirion[1,2,3]✉

Scientific Reports | (2022) 12:7050





OpenNeuro: Sharing raw and processed neuroimaging data



BIDS
BRAIN IMAGING DATA STRUCTURE

Validation Using BIDS

The Brain Imaging Data Structure (BIDS) is an emerging standard for the organization of neuroimaging data.

Want to contribute to BIDS?
Visit the Google discussion group to contribute.

DataLad

OpenNeuro Runs on DataLad

Want to access OpenNeuro datasets with DataLad? Visit the dataset collection on GitHub.

A data management solution built on Git and Git-

Simply sharing data is not sufficient

It must be shared in a way that makes it useful!

It’s easy to share data badly

Data Sharing and Management Snafu in 3 Short Acts

- I received the data, but when I opened it up it was in hexadecimal
- Yes, that is right
- I cannot read hexadecimal
- You asked for my data and I gave it to you. I have done what you asked.

Brain Imaging Data Structure (BIDS)

- A community-based open standard for neuroimaging data
  - A file organization standard
  - A metadata standard

BIDS
BRAIN IMAGING DATA STRUCTURE

SCIENTIFIC DATA

OPEN

SUBJECT CATEGORIES
» Data publication and archiving
» Research data

Received: 18 December 2015
Accepted: 19 May 2016
Published: 21 June 2016

The brain imaging data structure, a format for organizing and describing outputs of neuroimaging experiments

Krzysztof J. Gorgolewski[1], Tibor Auer[2], Vince D. Calhoun[3,4], R. Cameron Craddock[5,6], Samir Das[7], Eugene P. Duff[8], Guillaume Flandin[9], Satrajit S. Ghosh[10,11], Tristan Glatard[7,12], Yaroslav O. Halchenko[13], Daniel A. Handwerker[14], Michael Hanke[15,16], David Keator[17], Xiangrui Li[18], Zachary Michael[19], Camille Maumet[20], B. Nolan Nichols[21,22], Thomas E. Nichols[20,23], John Pellman[6], Jean-Baptiste Poline[24], Ariel Rokem[25], Gunnar Schaefer[1,26], Vanessa Sochat[27], William Triplett[1], Jessica A. Turner[3,28], Gaël Varoquaux[29] & Russell A. Poldrack[1]

The development of BIDS

- January 2015
  - Initial stakeholder meeting at Stanford (funded by INCF)
  - Initiated development of a draft standard
- September 2015
  - Draft standard posted to BIDS web site with 22 example datasets
  - Solicited feedback from community
- June 2016

BIDS Principles

- *Adoption is crucial*
  - Keep it as similar to existing practices as possible
    - Don’t let technology override usability!
  - Focus on engaging the community
- *Don’t reinvent the wheel*
  - Use existing standards when possible
- *80/20 rule*

From DICOM to BIDS

- dicomdir/
  - 1208200617178_22/
    - 1208200617178_22_8973.dcm
    - 1208200617178_22_8943.dcm
    - 1208200617178_22_2973.dcm
    - 1208200617178_22_8923.dcm
    - 1208200617178_22_4473.dcm
    - 1208200617178_22_8783.dcm
    - 1208200617178_22_7328.dcm
    - 1208200617178_22_9264.dcm

- my_dataset/
  - participants.tsv
  - sub-01/
    - anat/
      - sub-01_T1w.nii.gz
    - func/
      - sub-01_task-rest_bold.nii.gz
      - sub-01_task-rest_bold.json
    - dwi/
      - sub-01_dwi.nii.gz

The importance of automated validation

Summary

- 40 Files, 18.42kB
- 13 - Subjects
- 1 - Session

Available Tasks

- rhyme judgment

Available Modalities

- bold
- T1w

Your dataset is not a valid BIDS dataset.

BIDS Extensions

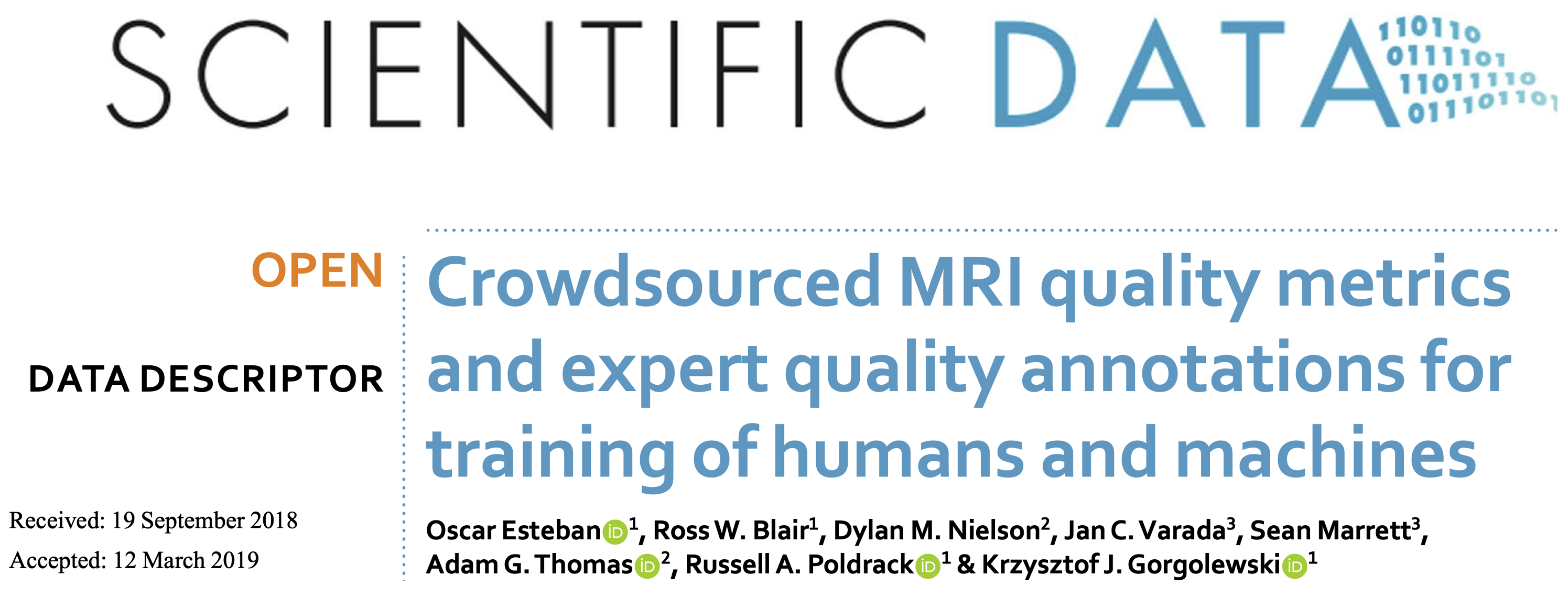
- BIDS was originally focused on structural/functional MRI data
- BIDS extension process allows extension of the standard through BIDS Extension Proposals (BEPS) initiated by the community
  - Patterned after the Python Enhancement Proposal (PEP) process

11 Completed BEPs:

BEP #	Title
BEP001	Quantitative MRI (qMRI)
BEP003	Common Derivatives
BEP005	Arterial Spin Labeling (ASL)
BEP006	Electroencephalography (EEG)
BEP007	Hierarchical Event Descriptor (HED) Tags
BEP008	Magnetoencephalography (MEG)

The growing usage of BIDS: An example

- MRIQC Web API
  - Crowdsourced database of MR QC metrics
  - QC metrics from ~375K unique BOLD scans and ~280K T1w scans as of June 2022
  - Publicly available: https://mriqc.nimh.nih.gov/


SCIENTIFIC DATA

OPEN

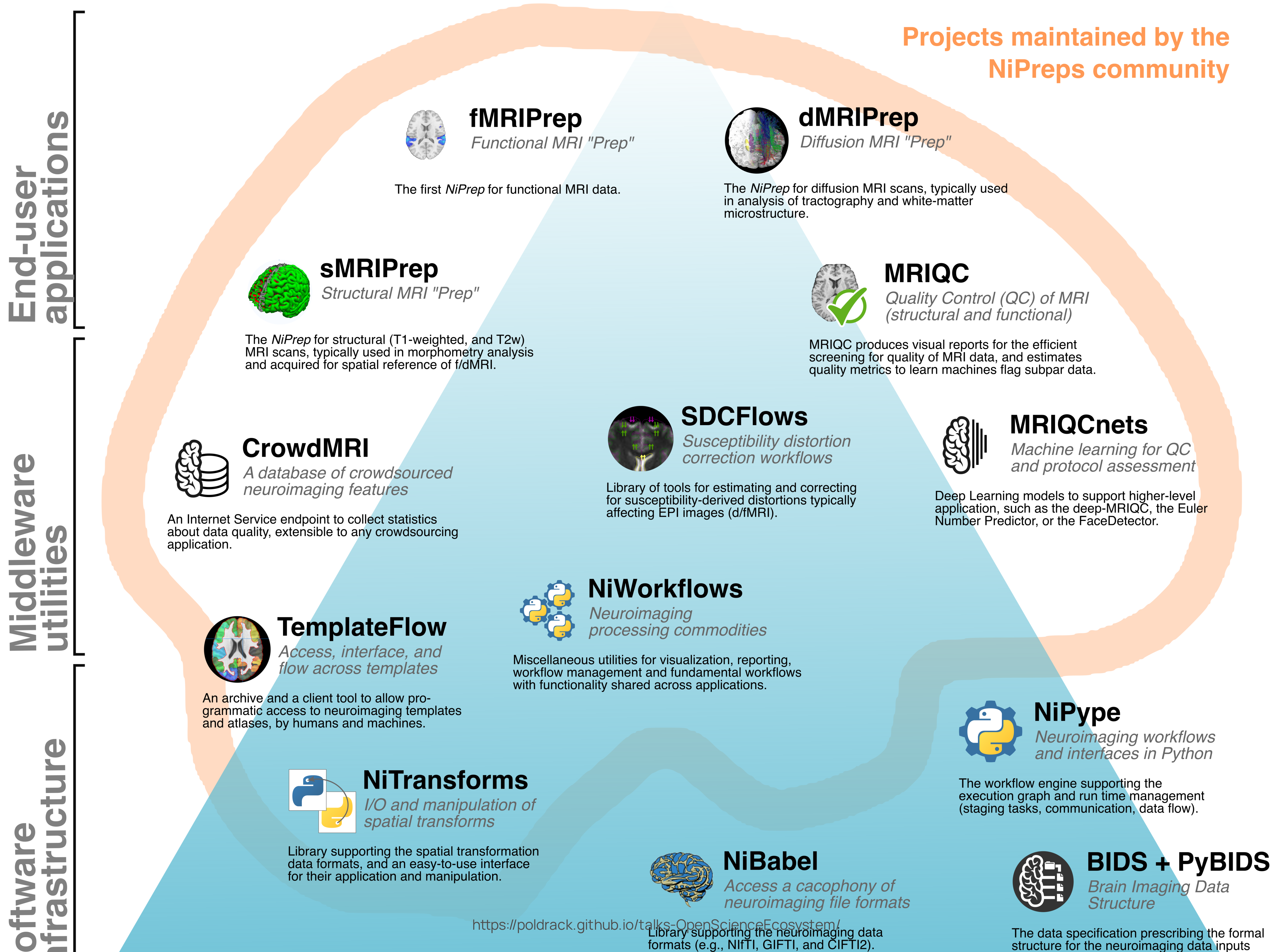
DATA DESCRIPTOR

Crowdsourced MRI quality metrics and expert quality annotations for training of humans and machines

Received: 19 September 2018
Accepted: 12 March 2019

Oscar Esteban[1], Ross W. Blair[1], Dylan M. Nielson[2], Jan C. Varada[3], Sean Marrett[3], Adam G. Thomas[2], Russell A. Poldrack[1] & Krzysztof J. Gorgolewski[1]

BIDS enables a growing open-source software ecosystem



RESEARCH ARTICLE

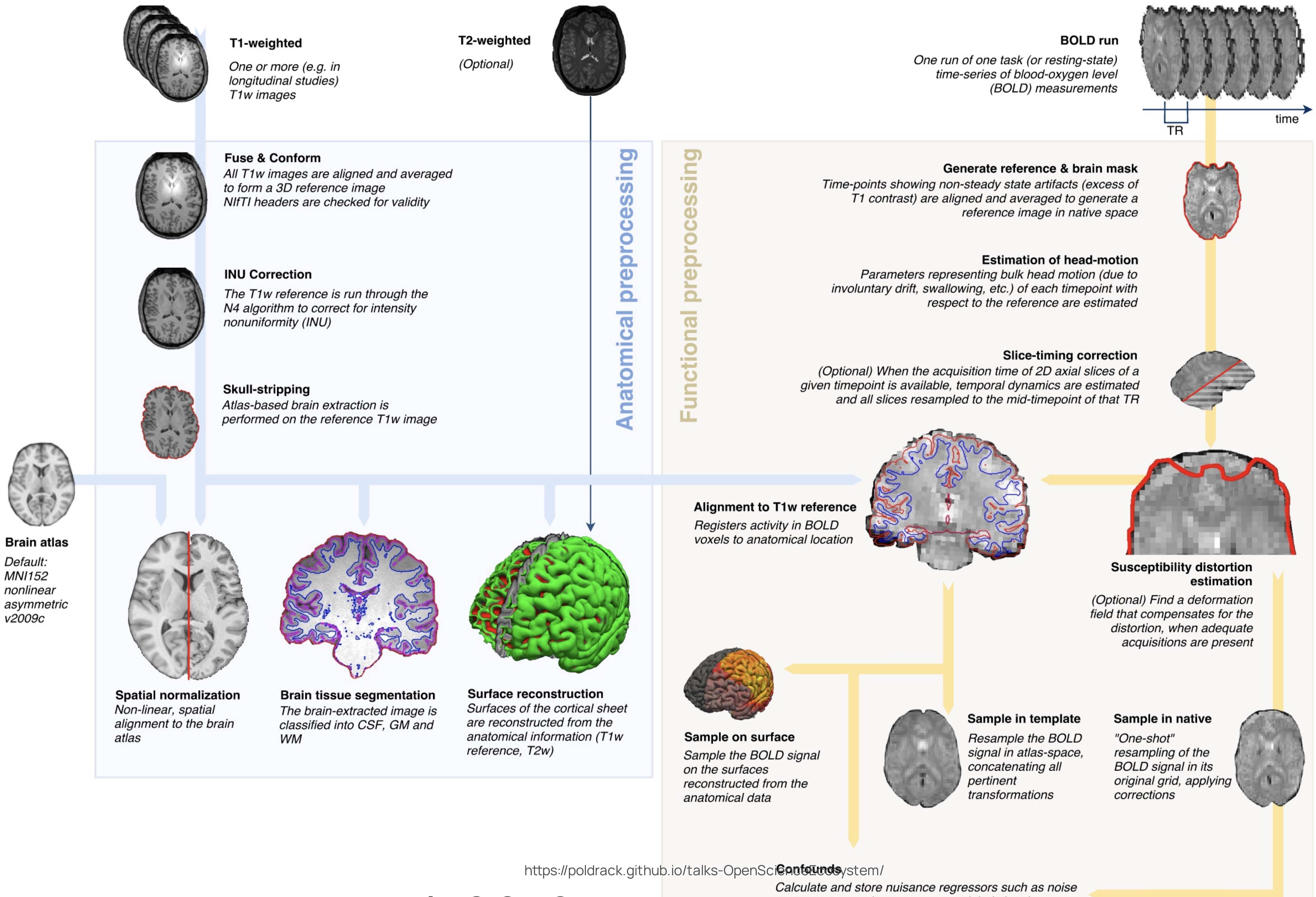
BIDS apps: Improving ease of use, accessibility, and reproducibility of neuroimaging data analysis methods

Krzysztof J. Gorgolewski[1]*, Fidel Alfaro-Almagro[2], Tibor Auer[3], Pierre Bellec[4,5], Mihai Capotă[6], M. Mallar Chakravarty[7,8], Nathan W. Churchill[9], Alexander Li Cohen[10], R. Cameron Craddock[11,12], Gabriel A. Devenyi[7,8], Anders Eklund[13,14,15], Oscar Esteban[1], Guillaume Flandin[16], Satrajit S. Ghosh[17,18], J. Swaroop Guntupalli[19], Mark Jenkinson[2], Anisha Keshavan[20], Gregory Kiar[21,22], Franziskus Liem[23], Pradeep Reddy Raamana[24,25], David Raffelt[26], Christopher J. Steele[7,8], Pierre-Olivier Quirion[15], Robert E. Smith[26], Stephen C. Strother[24,25], Gaël Varoquaux[27], Yida Wang[6], Tal Yarkoni[28], Russell A. Poldrack[1]

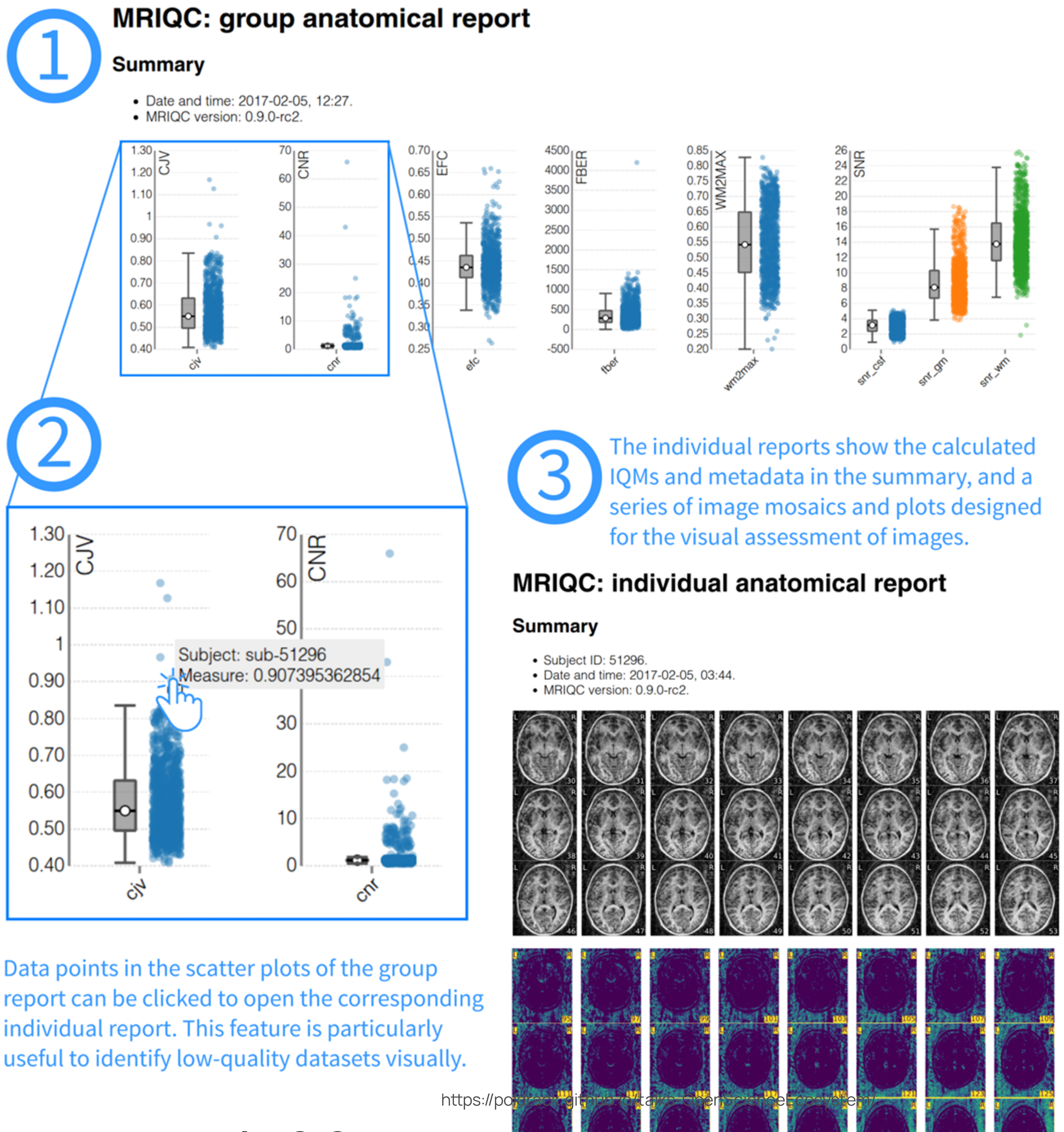
PLOS Computational Biology | https://doi.org/10.1371/journal.pcbi.1005209 March 9, 2017

- Containerized applications that can be run on a BIDS dataset
  - Containers provide ease of use as well as better reproducibility

fMRIprep: Robust preprocessing of fMRI data

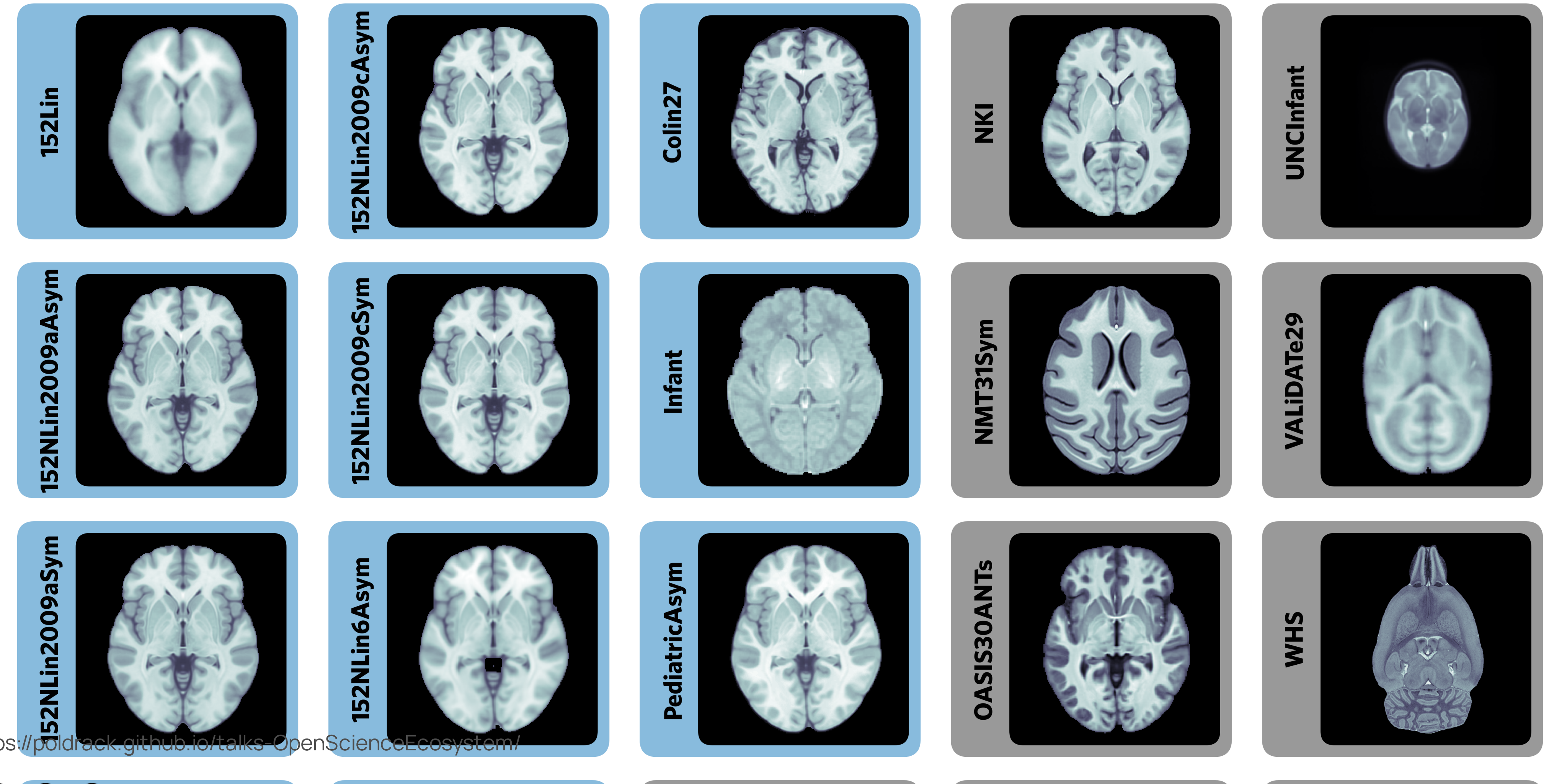


MRIQC: MRI quality control for BIDS data

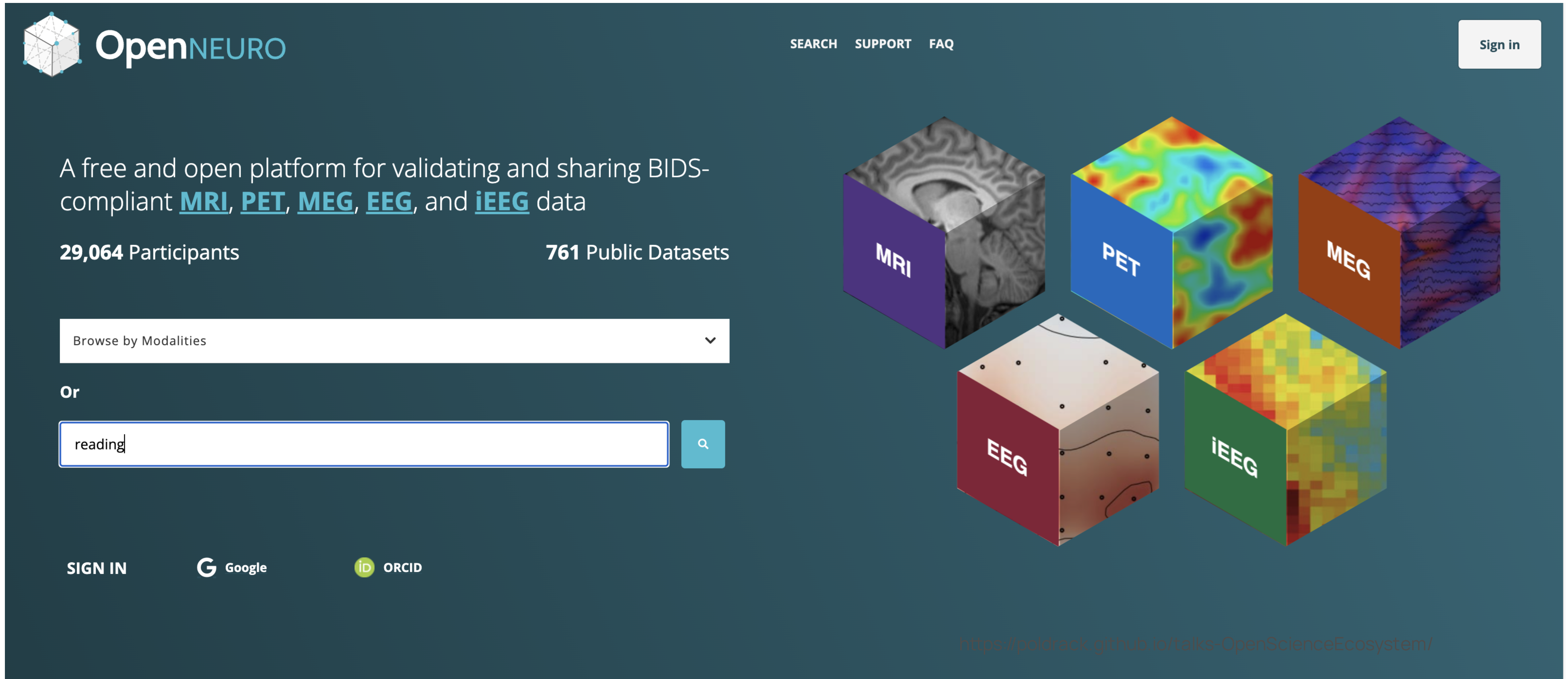


Tenmplateflow: FAIR Sharing of Neuroimaging Templates

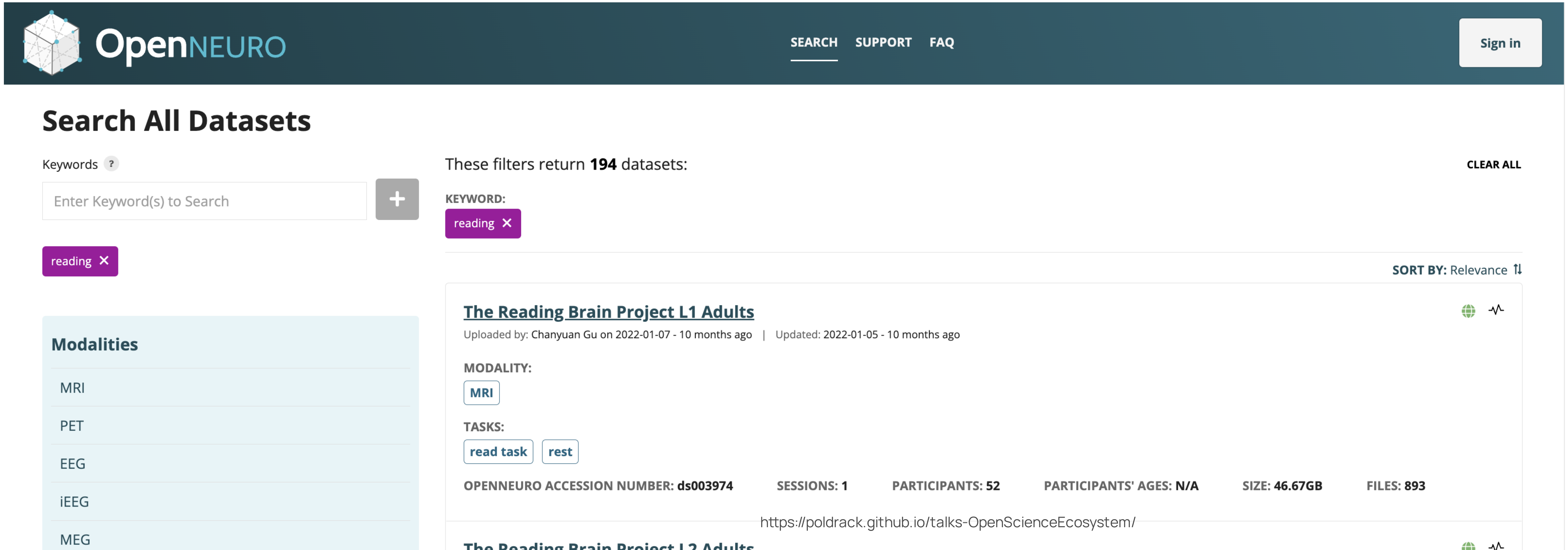
- Templates and atlases are commonly used in neuroimaging
- There is a significant lack of clarity in the use of these templates
  - There are numerous versions of the widely used “MNI



OpenNeuro: A BRAIN Initiative archive for BIDS data

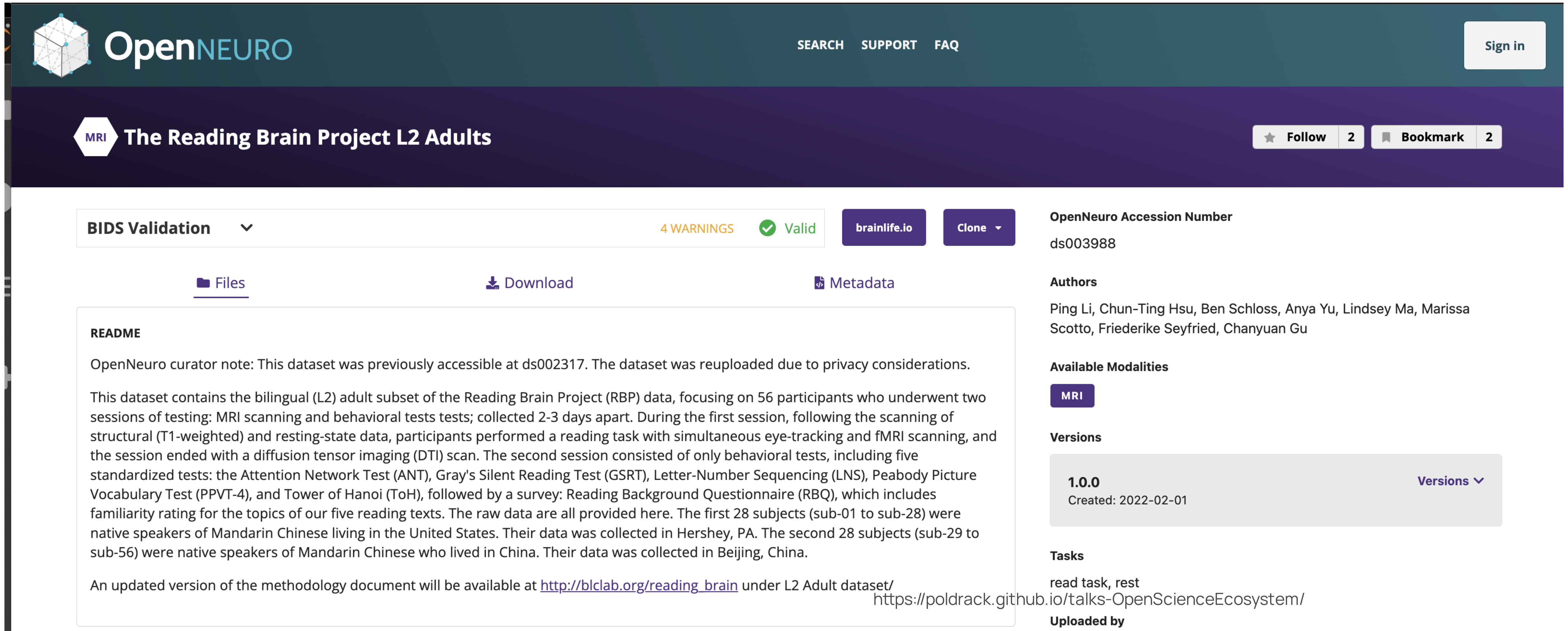


- Supports sharing of any validated BIDS dataset

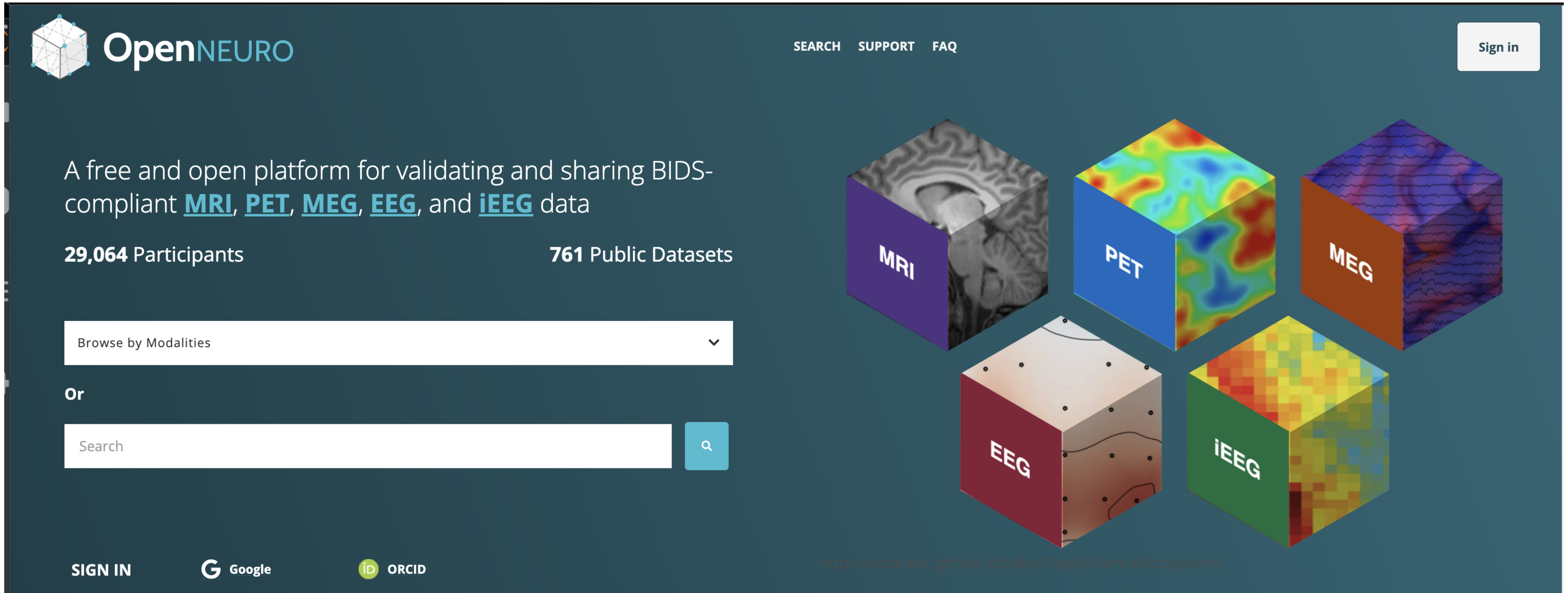

OpenNEURO
SEARCH
SUPPORT
FAQ
Sign in
Search All Datasets
Keywords
Enter Keyword(s) to Search
reading
Modalities
MRI
PET
EEG
iEEG
MEG
These filters return 194 datasets:
CLEAR ALL
KEYWORD:
reading
SORT BY: Relevance
The Reading Brain Project L1 Adults
Uploaded by: Chanyuan Gu on 2022-01-07 - 10 months ago | Updated: 2022-01-05 - 10 months ago
MODALITY:
MRI
TASKS:
read task
rest
OPENNEURO ACCESSION NUMBER: ds003974
SESSIONS: 1
PARTICIPANTS: 52
PARTICIPANTS' AGES: N/A
SIZE: 46.67GB
FILES: 893

Each shared dataset is versioned and

receives a persistent identifier (DOI)



Any valid BIDS dataset can be shared via OpenNeuro


OpenNEURO
SEARCH
SUPPORT
FAQ
Sign in
A free and open platform for validating and sharing BIDS-compliant MRI, PET, MEG, EEG, and iEEG data
29,064 Participants
761 Public Datasets
Browse by Modalities
Or
Search
MRI
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MEG
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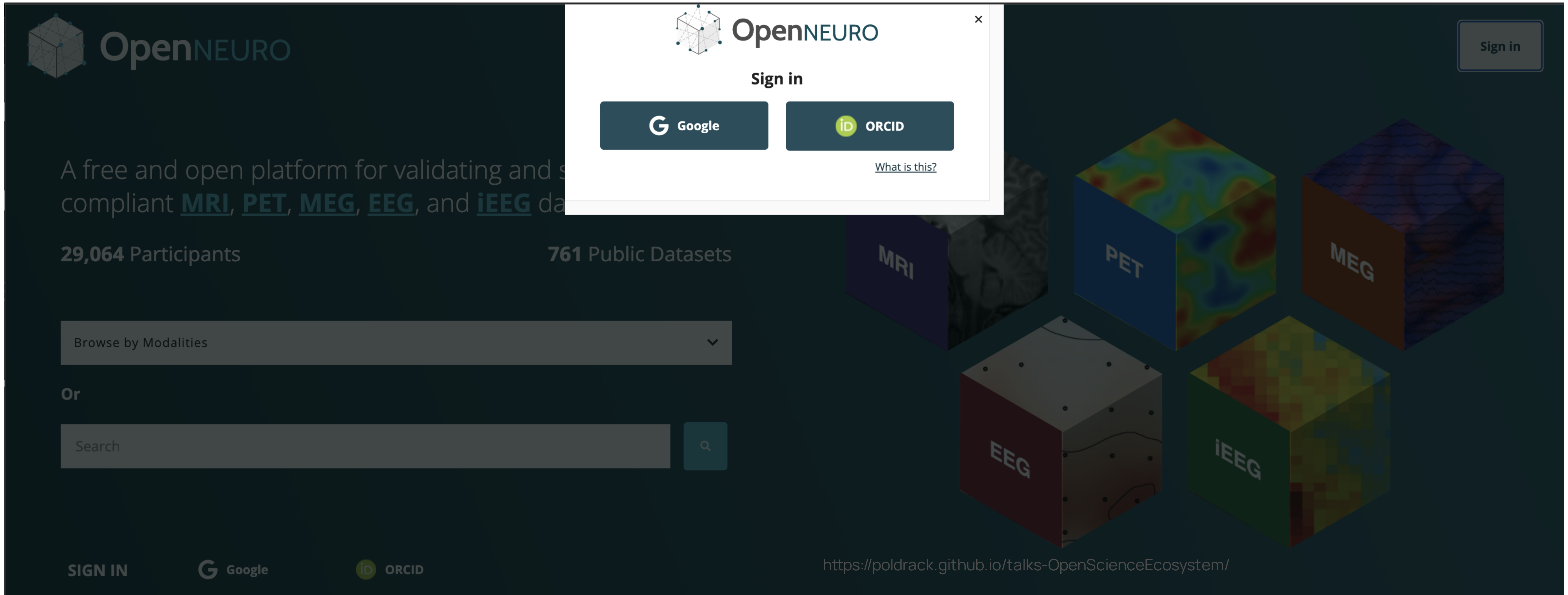

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What is this?
Sign in
A free and open platform for validating and s
compliant MRI, PET, MEG, EEG, and iEEG da
29,064 Participants
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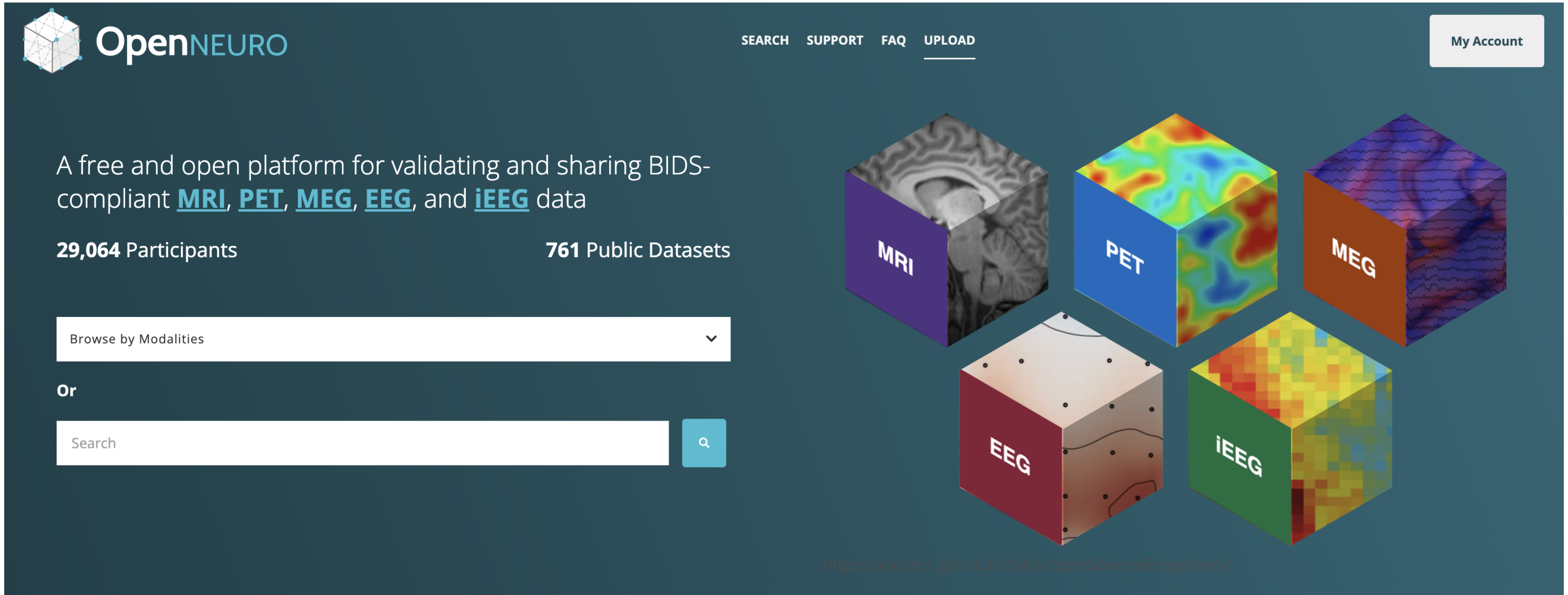
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My Account
A free and open platform for validating and sharing BIDS-compliant MRI, PET, MEG, EEG, and iEEG data
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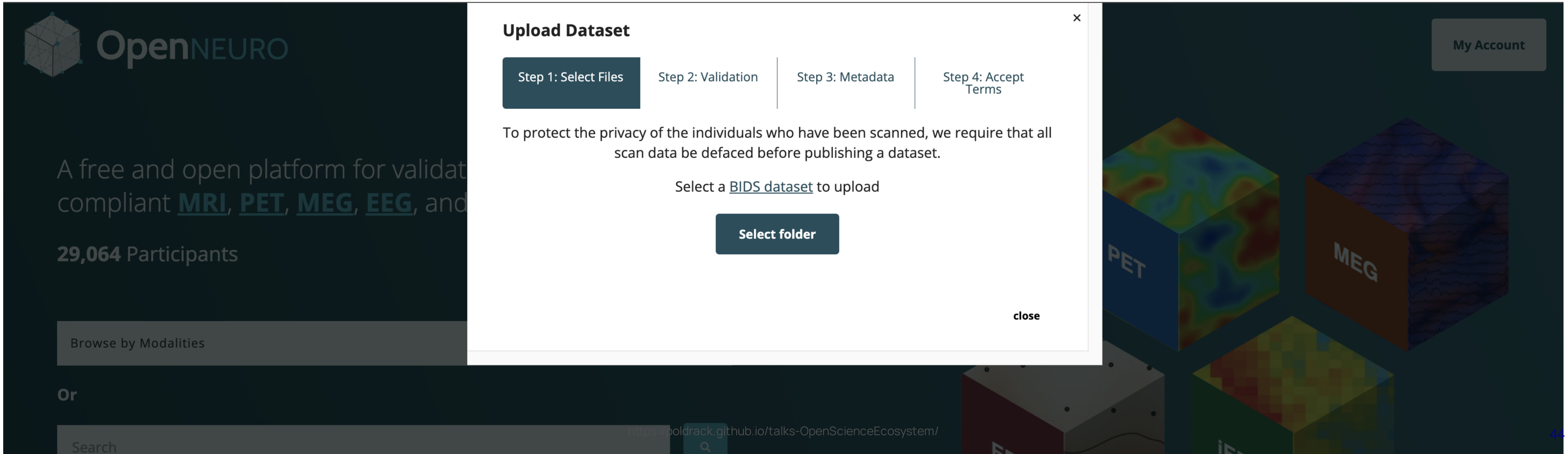
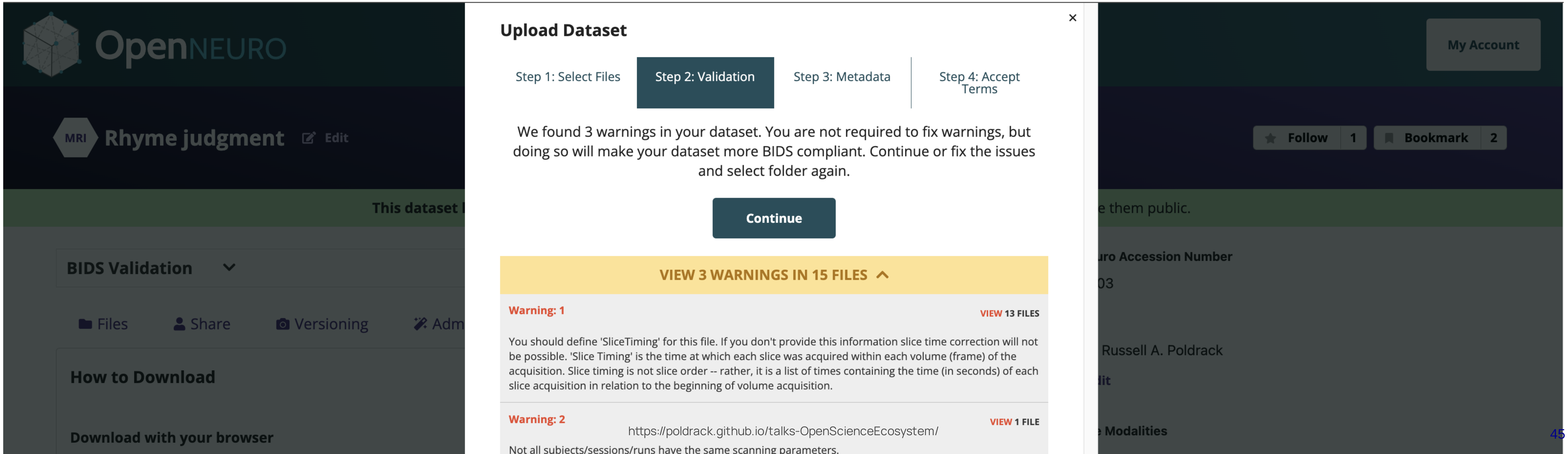

OpenNEURO
My Account
Upload Dataset
×
Step 1: Select Files
Step 2: Validation
Step 3: Metadata
Step 4: Accept Terms
To protect the privacy of the individuals who have been scanned, we require that all scan data be defaced before publishing a dataset.
Select a BIDS dataset to upload
Select folder
close
A free and open platform for validat
compliant MRI, PET, MEG, EEG, and
29,064 Participants
Browse by Modalities
Or
Search
PET
MEG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BIDS Validation
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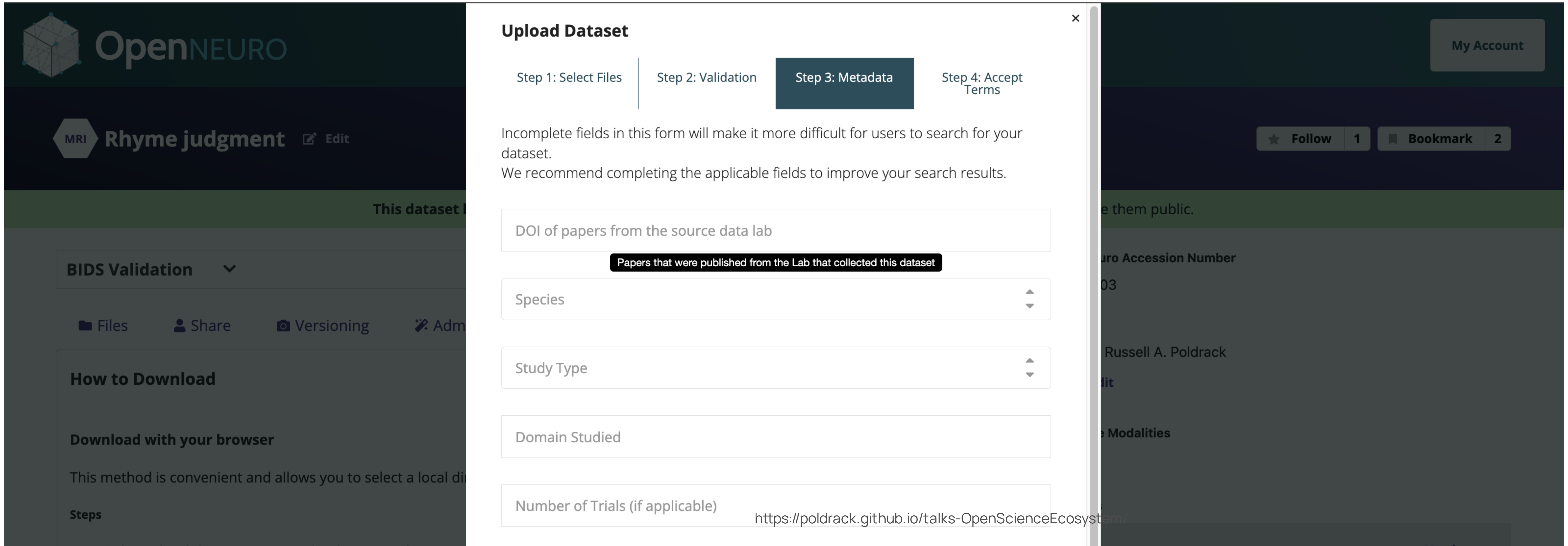
Modalities
Upload Dataset
Step 1: Select Files
Step 2: Validation
Step 3: Metadata
Step 4: Accept Terms
We found 3 warnings in your dataset. You are not required to fix warnings, but doing so will make your dataset more BIDS compliant. Continue or fix the issues and select folder again.
Continue
VIEW 3 WARNINGS IN 15 FILES
Warning: 1
VIEW 13 FILES
You should define 'SliceTiming' for this file. If you don't provide this information slice time correction will not be possible. 'Slice Timing' is the time at which each slice was acquired within each volume (frame) of the acquisition. Slice timing is not slice order -- rather, it is a list of times containing the time (in seconds) of each slice acquisition in relation to the beginning of volume acquisition.
Warning: 2
VIEW 1 FILE
Not all subjects/sessions/runs have the same scanning parameters.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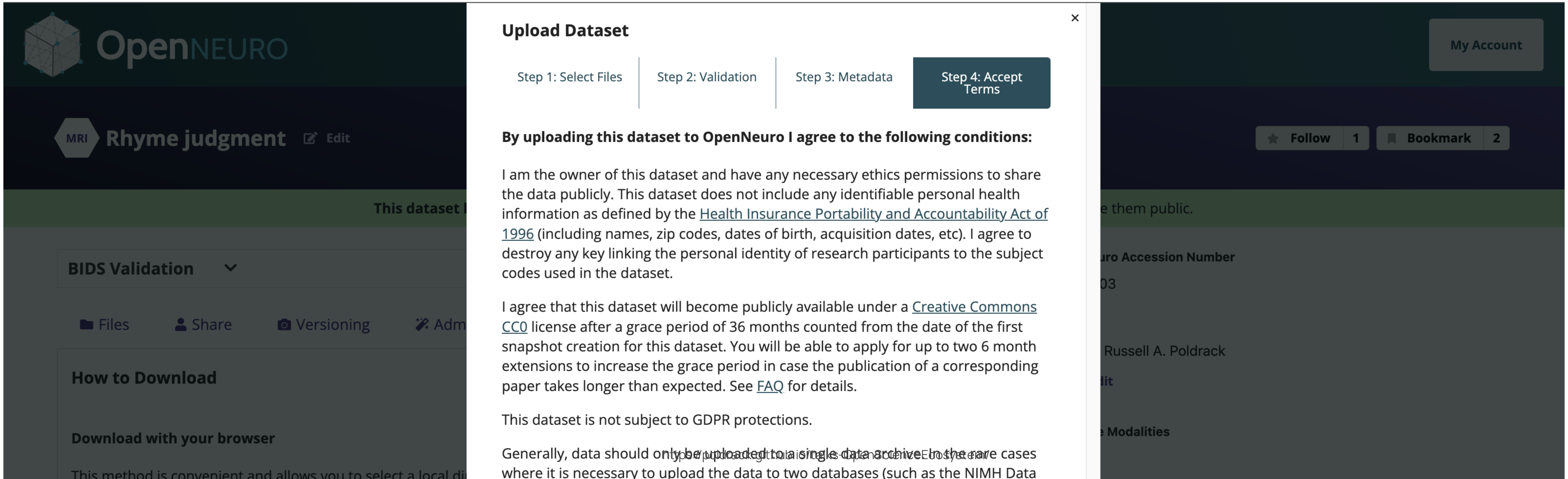
Incomplete fields in this form will make it more difficult for users to search for your dataset.
We recommend completing the applicable fields to improve your search results.
DOI of papers from the source data lab
Papers that were published from the Lab that collected this dataset
Species
Study Type
Domain Studied
Number of Trials (if applicable)


OpenNEURO
My Account
Upload Dataset
Step 1: Select Files
Step 2: Validation
Step 3: Metadata
Step 4: Accept Terms
By uploading this dataset to OpenNeuro I agree to the following conditions:
I am the owner of this dataset and have any necessary ethics permissions to share the data publicly. This dataset does not include any identifiable personal health information as defined by the Health Insurance Portability and Accountability Act of 1996 (including names, zip codes, dates of birth, acquisition dates, etc). I agree to destroy any key linking the personal identity of research participants to the subject codes used in the dataset.
I agree that this dataset will become publicly available under a Creative Commons CC0 license after a grace period of 36 months counted from the date of the first snapshot creation for this dataset. You will be able to apply for up to two 6 month extensions to increase the grace period in case the publication of a corresponding paper takes longer than expected. See FAQ for details.
This dataset is not subject to GDPR protections.
Generally, data should only be uploaded to a single data archive. In the rare cases where it is necessary to upload the data to two databases (such as the NIMH Data
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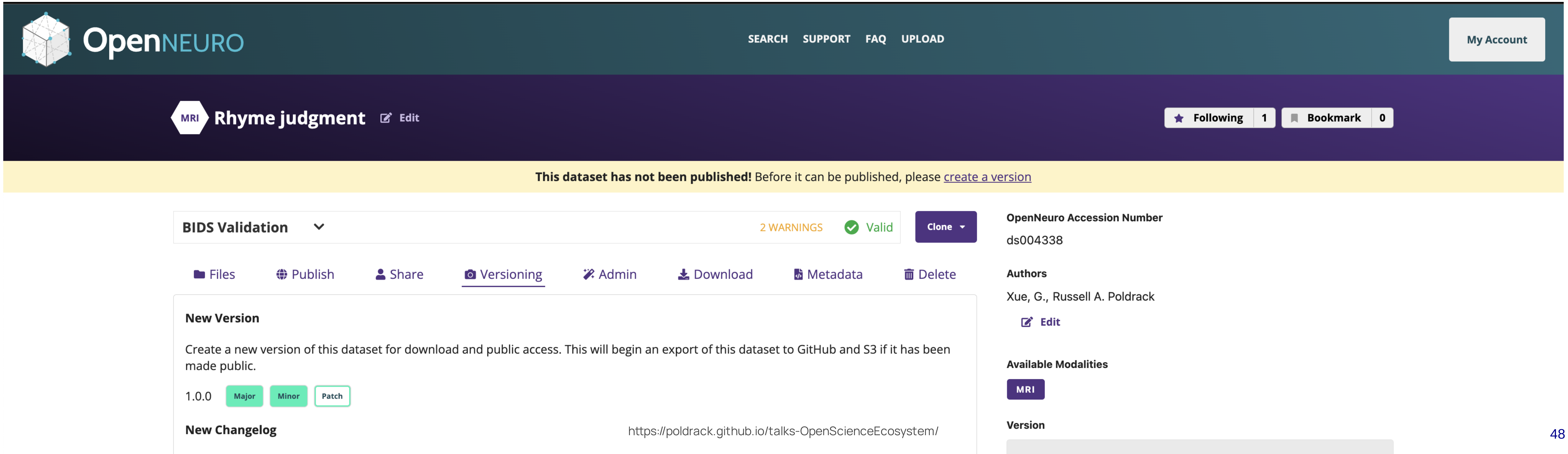
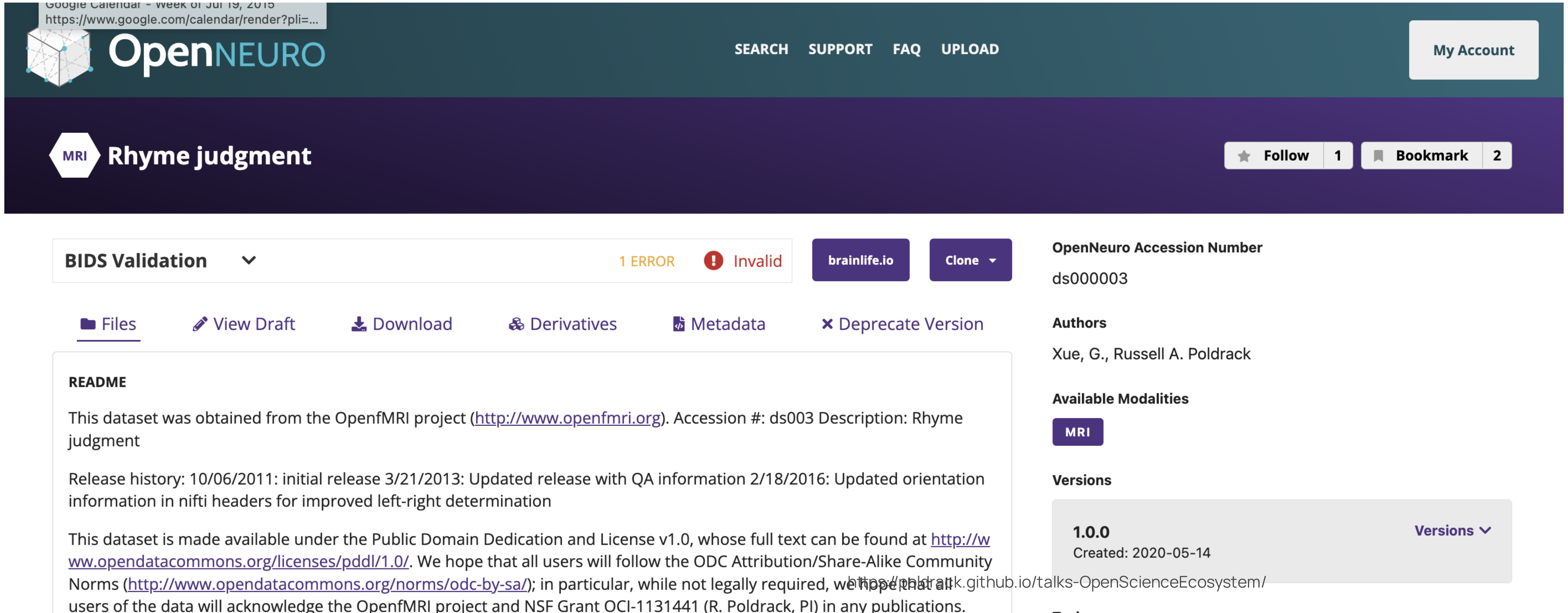


https://poldrack.github.io/talks-OpenScienceEcosystem/


https://www.google.com/calendar/render?pli=...
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SEARCH SUPPORT FAQ UPLOAD
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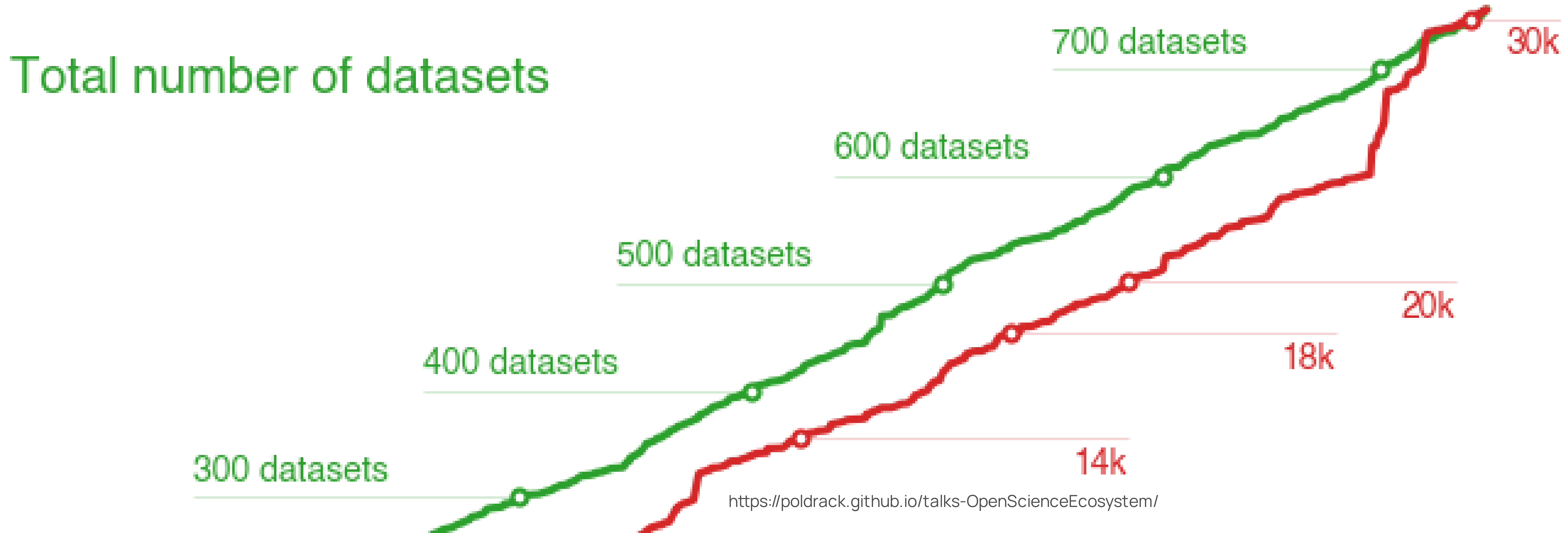
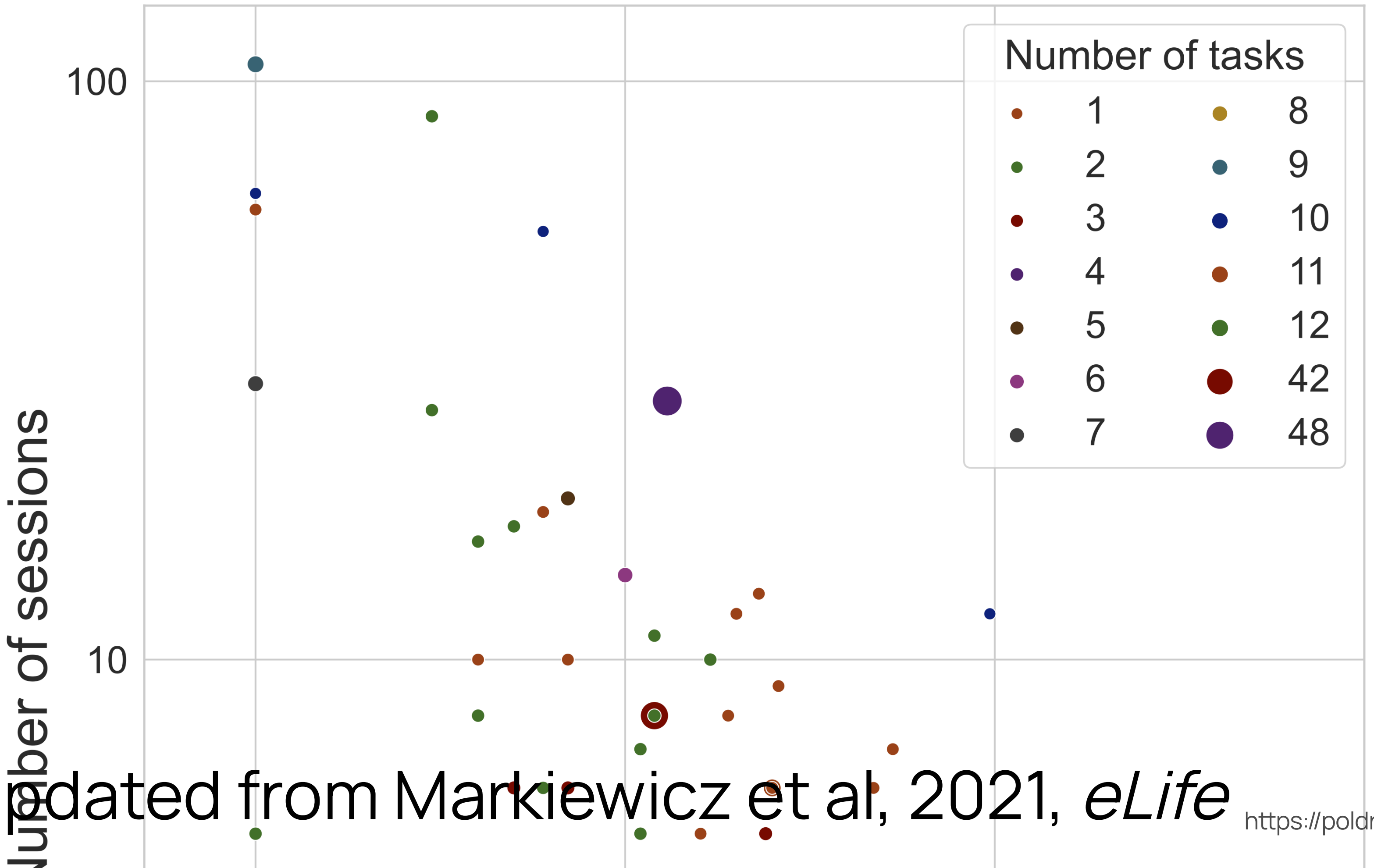
README
This dataset was obtained from the OpenfMRI project (http://www.openfmri.org). Accession #: ds003 Description: Rhyme judgment
Release history: 10/06/2011: initial release 3/21/2013: Updated release with QA information 2/18/2016: Updated orientation information in nifti headers for improved left-right determination
This dataset is made available under the Public Domain Dedication and License v1.0, whose full text can be found at http://www.opendatacommons.org/licenses/pddl/1.0/. We hope that all users will follow the ODC Attribution/Share-Alike Community Norms (http://www.opendatacommons.org/norms/odc-by-sa/); in particular, while not legally required, we
OpenNeuro Accession Number
ds000003
Authors
Xue, G., Russell A. Poldrack
Available Modalities
MRI
Versions
1.0.0
Created: 2020-05-14
Versions

The growth of OpenNeuro



https://poldrack.github.io/talks-OpenScienceEcosystem/

The diversity of OpenNeuro datasets



Datatype	#
mri - anat	597
mri - func	521
eeg	120
mri - dwi	67
meg	30
ieeg	17
beh	13

Species	#
Human	676
Mouse	20
Rat	12
NHP	2
phantoms	1
Juvenile pigs	1
Human, Mouse	1

updated from Markiewicz et al, 2021, *eLife*

Scholarly reuse of OpenNeuro datasets

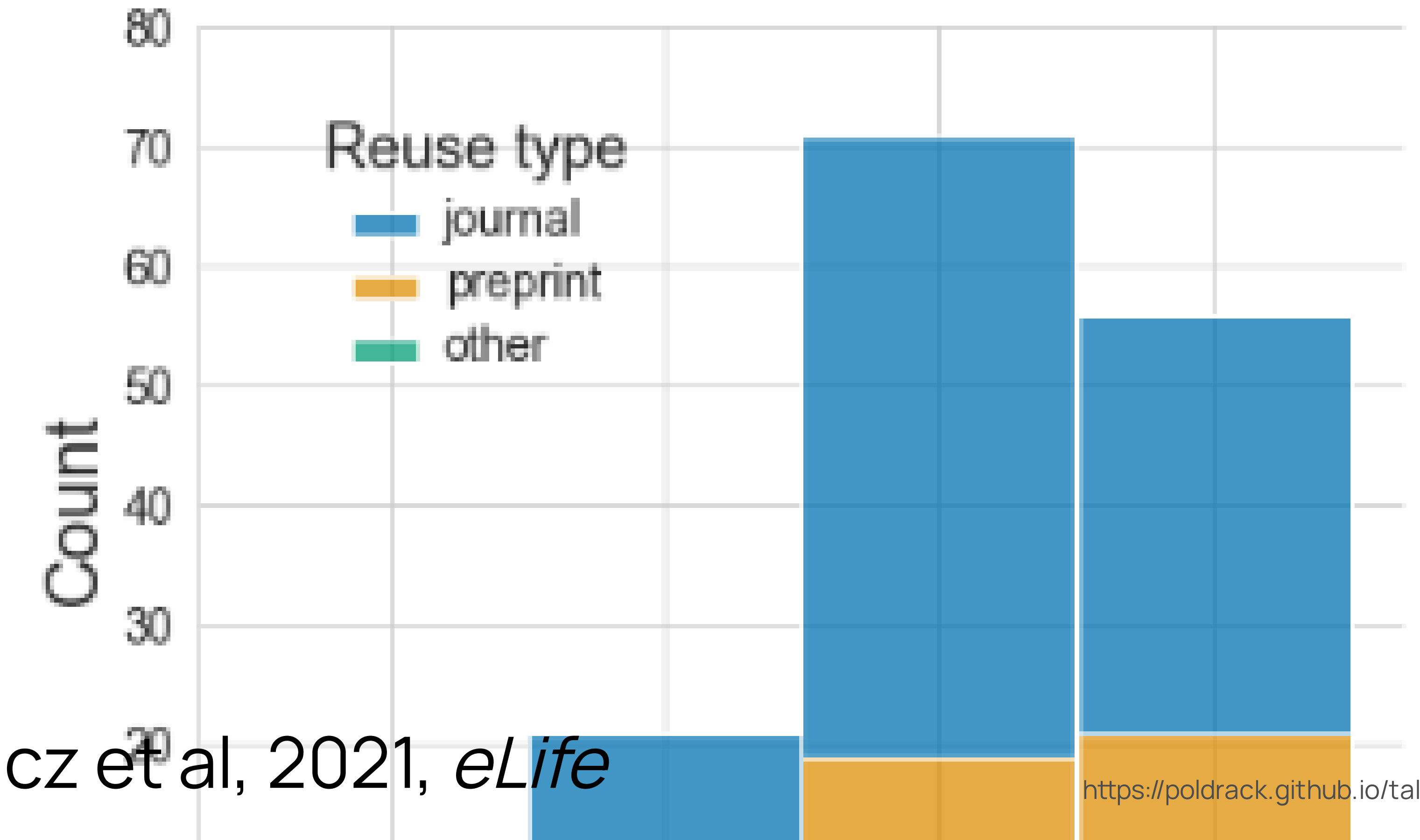
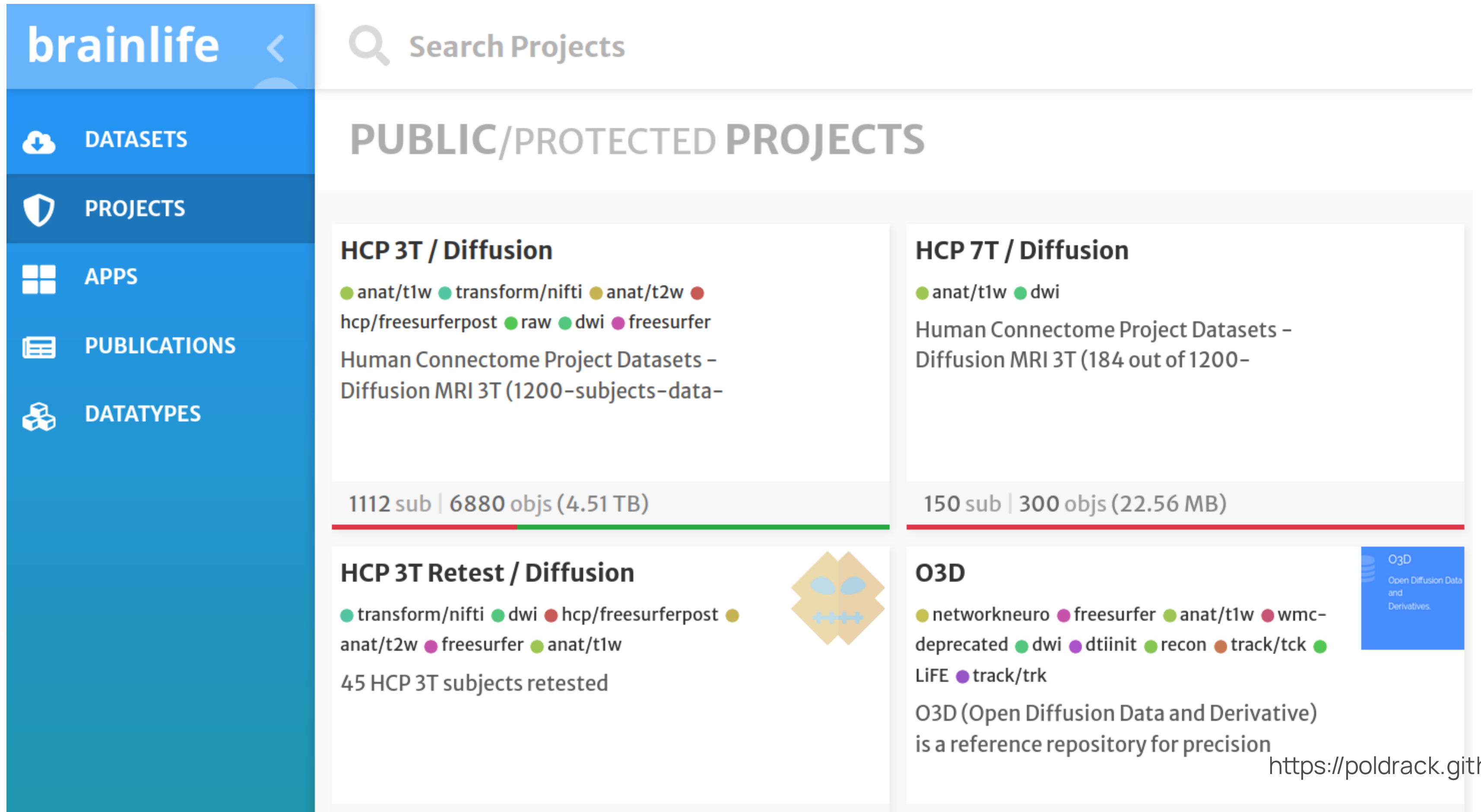


Figure 5. Published reuses of OpenNeuro datasets, split by the type of reuse. Note that the final bar includes only reuses identified through June 2021.

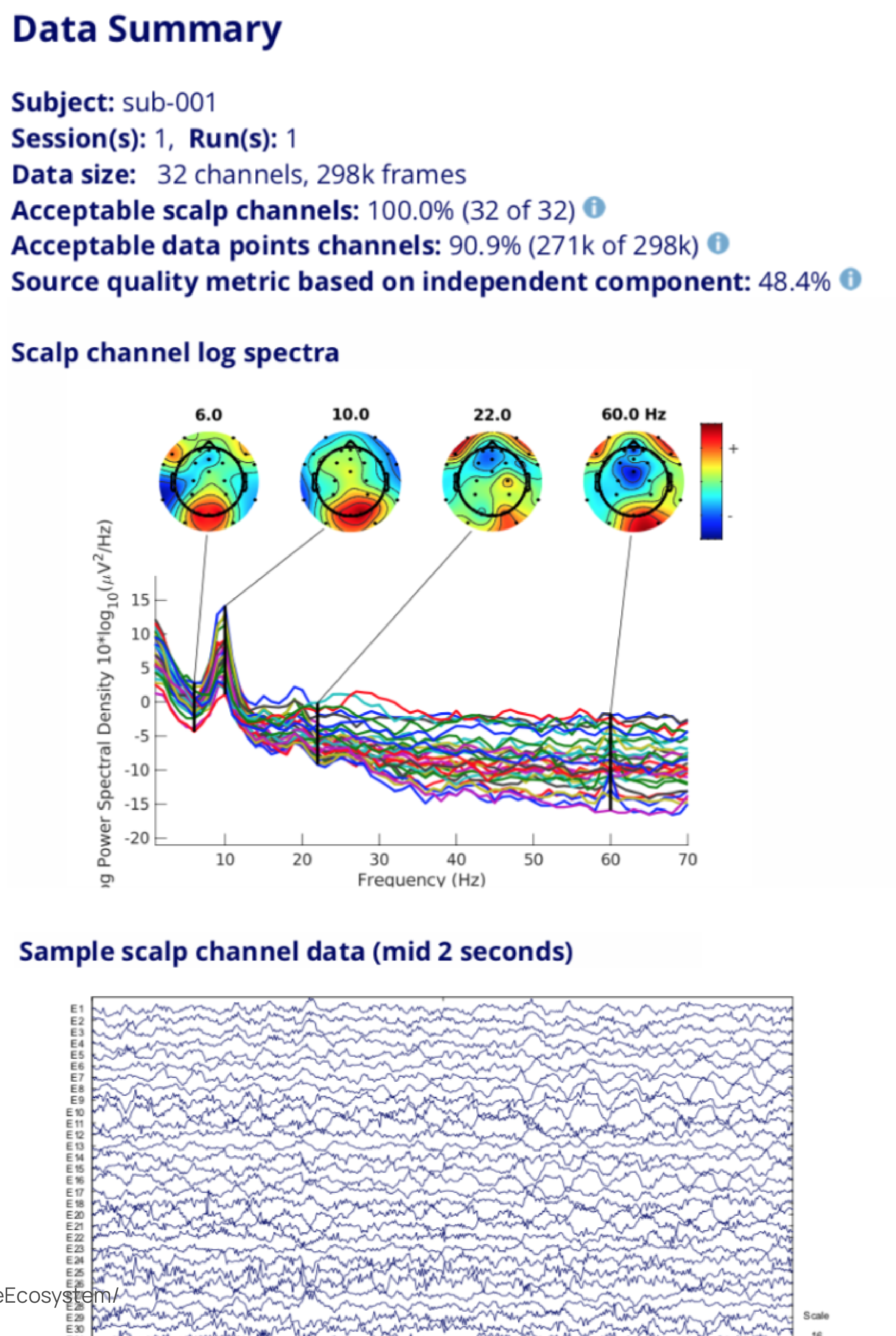
Markiewicz et al, 2021, *eLife*

Processing of OpenNeuro data

brainlife.io: processing of MRI data

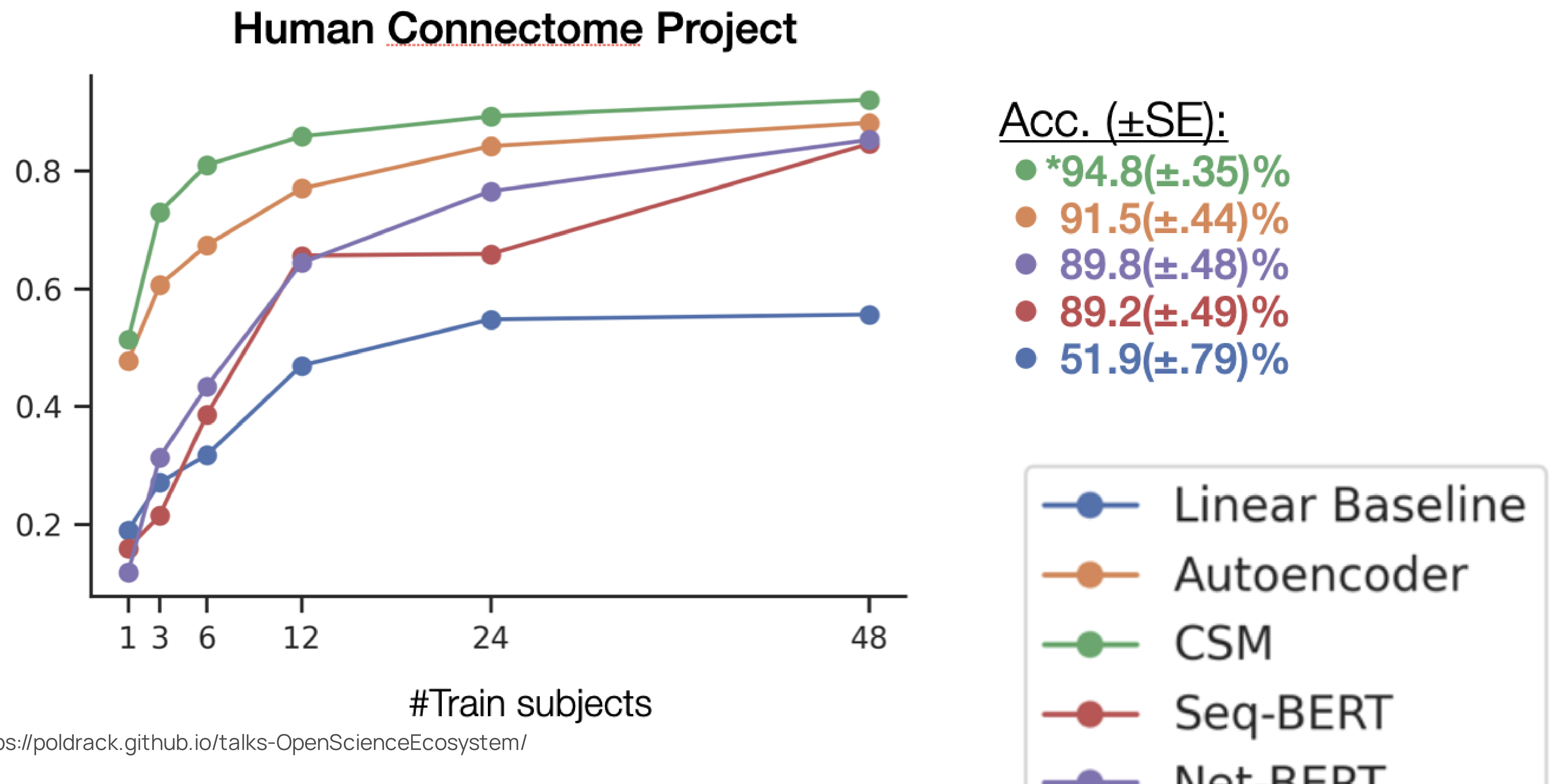


NEM ... ta



Example of OpenNeuro reuse

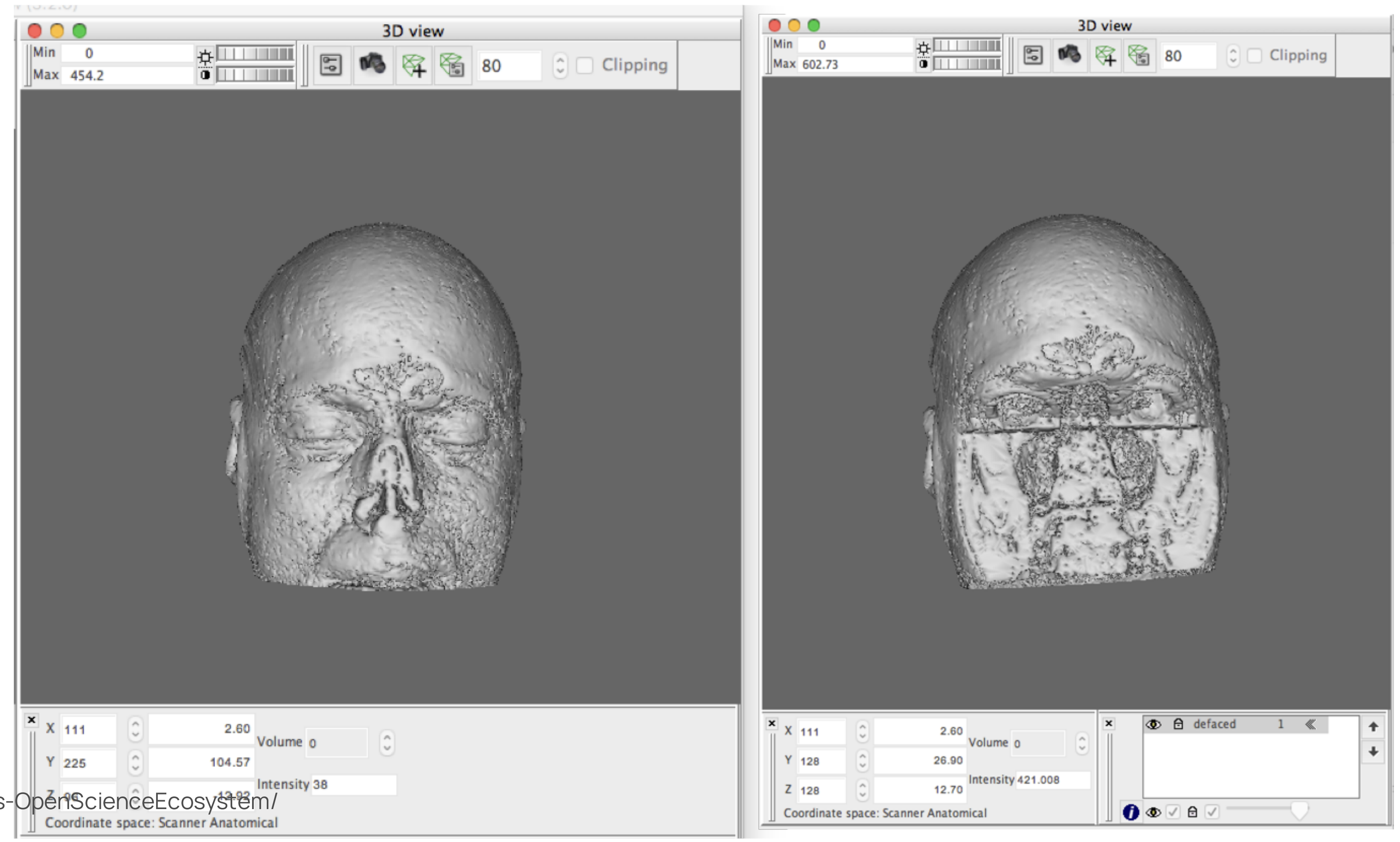
- A challenge for decoding brain activity from fMRI data is that most datasets are very small
- We used OpenNeuro to train a "foundation model"
  - A pre-trained model that can be used as a starting point for decoding models on smaller datasets
- We pre-train models on broad fMRI data from OpenNeuro: 11,980 experimental



Thomas, Ré, & Poldrack, 2022, *NeurIPS*

Challenges to open sharing

- All OpenNeuro MRI datasets must be *defaced*
  - To reduce risk of reidentification
- There is increasing risk that subjects might be reidentified even after defacing using advanced face recognition systems + face imputation tools (Schwartz et al., 2021)
- If the risk continues to rise, it may become necessary to move away from open sharing
  - This would be a huge loss for researchers,



Keys to success in neuroimaging data sharing

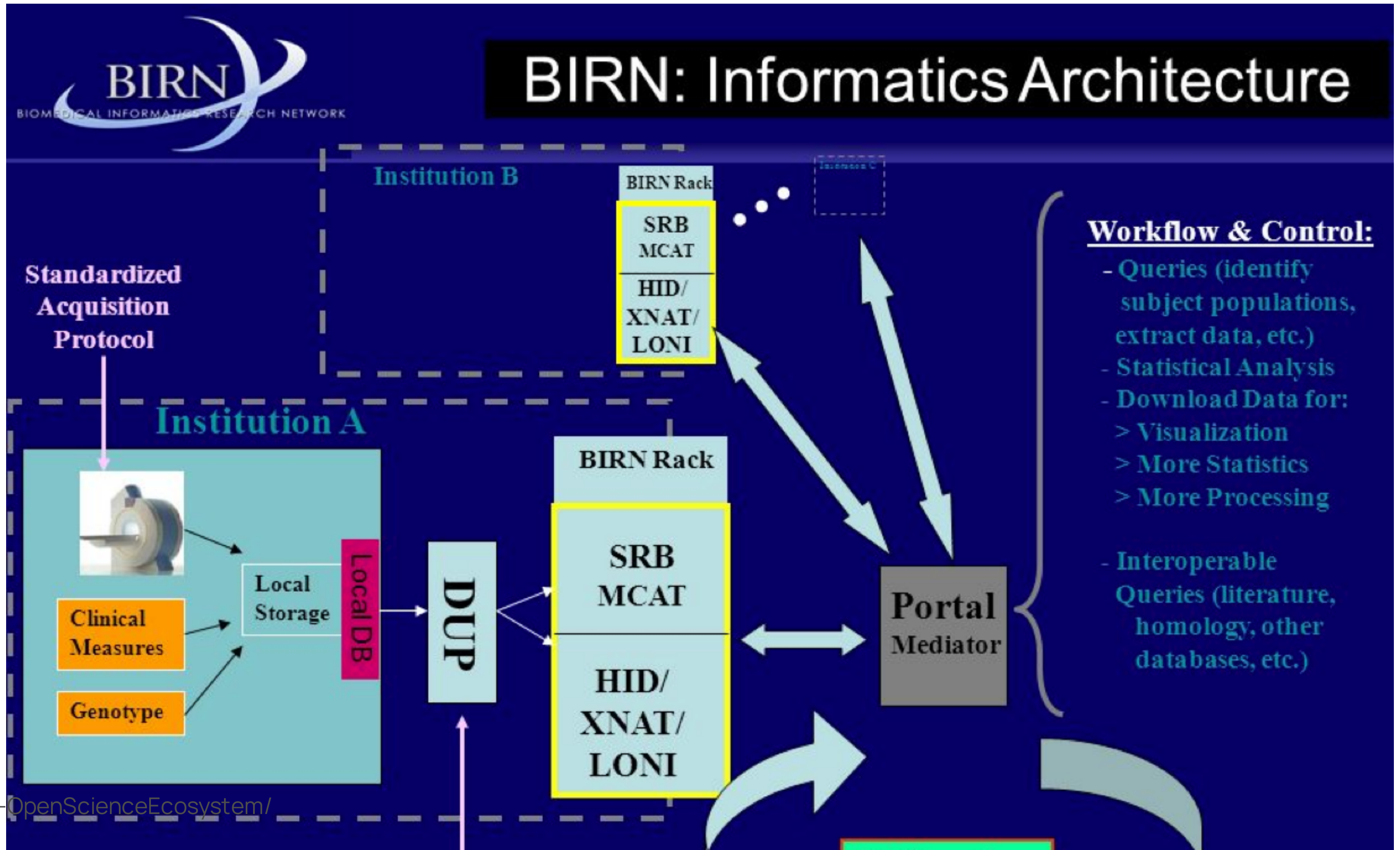
- *Data are digital end-to-end*
  - Minimizes manual steps in the process
- *Standardized file formats and data standards*
  - Makes data immediately usable by anyone
  - Reduces burden of curation and preparation
- *Demonstrated scientific utility*
- *Numerous success stories*

Lessons learned

- Community buy-in is essential
  - Mandates put in place before the community is ready can backfire
    - Unless they have overwhelmingly powerful advocates, as in genomics
  - Important that sharing advocates are members of community and eat their own dog food

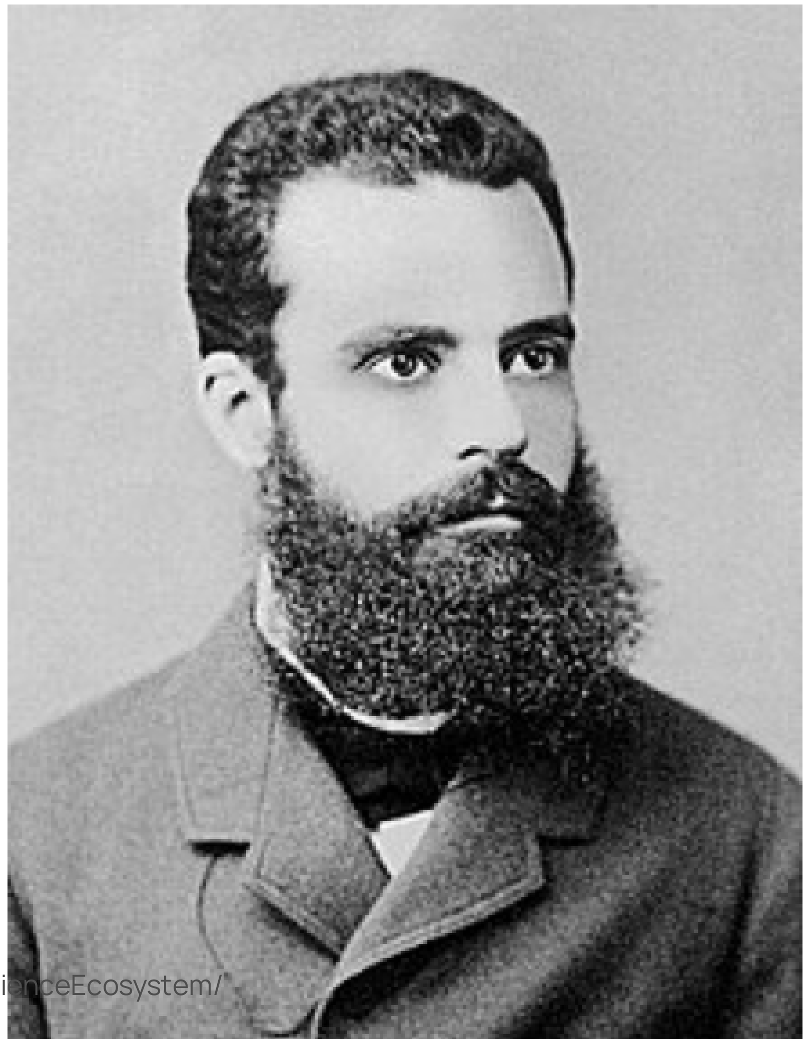
Lessons learned

- Keep it simple and as close to standard practice as possible
  - Overengineered solutions have generally failed
  - If there are more than 2 acronyms...



Lessons learned

- Don't let the perfect be the enemy of the good
  - 20% of the effort will cover 80% of the datasets - focus on these!
  - There is a long tail of edge cases with loud advocates



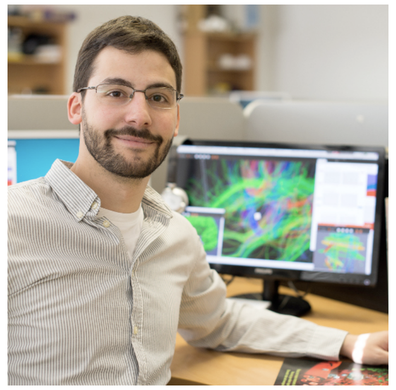
Conclusions

- The field of neuroimaging has built an model ecosystem for open science and data sharing
- Infrastructure is critical to ease friction
- Community engagement has been key to adoption
- Need to keep the tools as close as possible to current practice

The Poldrack Lab

OpenNeuro Team

Funding

THE BRAIN INITIATIVE
NATIONAL INSTITUTES OF HEALTH

NSF

ljaf
laura and john arnold foundation®

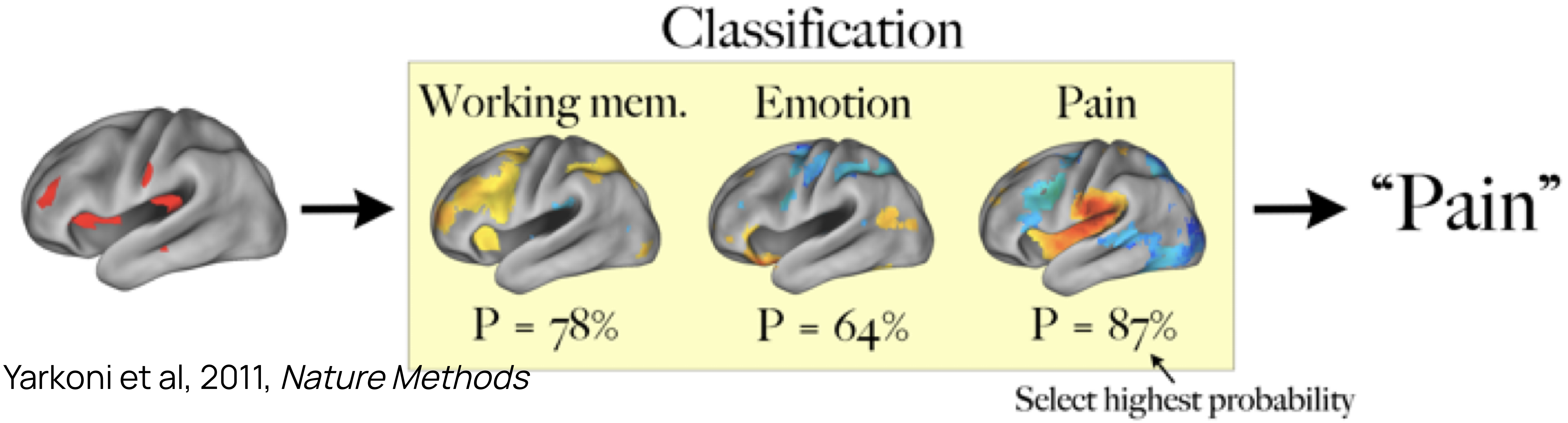
NIH
National Institute
of Mental Health

Collaborators

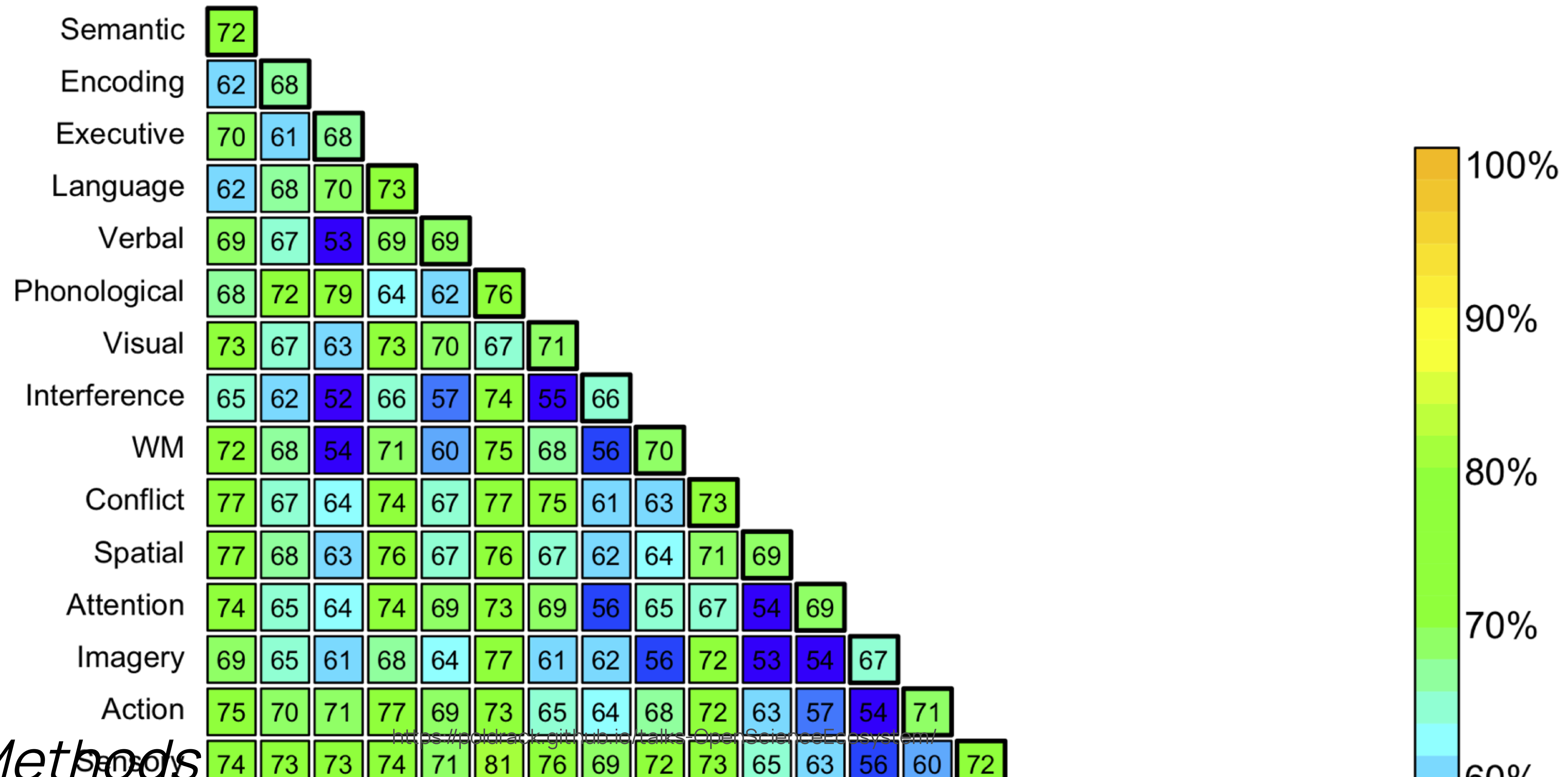
Meta-analytic decoding using Neurosynth

- Given 2+ terms, can determine which is most likely given the data
- Naive Bayes classifier: assumes that all features (voxels) are independent; selects the most probable class
- Can apply this to any activation map—studies, individual subjects, etc.



Yarkoni et al, 2011, *Nature Methods*

- Cross-validated classification of all studies in database
- Select 25 high-frequency terms
- Pairwise classification: how well can we distinguish between the presence of each pair of terms?



Yarkoni et al. 2011, *Nature Methods*