



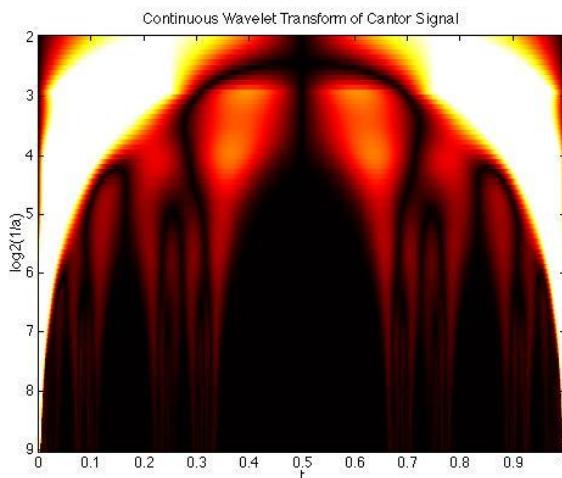
# SPM and Data Sharing

*Guillaume Flandin*

Wellcome Trust Centre for Neuroimaging  
University College London

Brainhack  
Warwick, 3<sup>rd</sup> March 2017

# Reproducible Research



## WaveLab and Reproducible Research

*Jonathan B. Buckheit and David L. Donoho*

Stanford University, Stanford CA 94305, USA

### Abstract

WAVELAB is a library of MATLAB routines for wavelet analysis, wavelet-packet analysis, cosine-packet analysis and matching pursuit. The library is available free of charge over the Internet. Versions are provided for Macintosh, UNIX and Windows machines.

WAVELAB makes available, in one package, all the code to reproduce all the figures in our published wavelet articles. The interested reader can inspect the source code to see exactly what algorithms were used, how parameters were set in producing our figures, and can then modify the source to produce variations on our results. WAVELAB has been developed, in part, because of exhortations by Jon Claerbout of Stanford that computational scientists should engage in "really reproducible" research.

*"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 environment and the complete set of instructions which generated the figures."*

# Reproducible Research

- ❑ Internet: *distribution, collaboration.*
- ❑ Freeware: *GNU licences, copyleft.*
- ❑ Quantitative Programming Environments: *high-level, fourth generation programming languages (MATLAB, R, Python, Julia, ...)*

In the future, we can envision that publication in computational sciences will change so that reproducibility is integrated into process. One way to do this would be if journals were fully electronic, and if we adopted hypermedia techniques. Then every computationally-generated figure and every computationally-generated table in an article would become linked to the code and the computational environment that produced the figure. If one were interested in a figure, one would click on it with a mouse, and a new window would instantly appear, containing the code that the author of the article used to create the figure. To reproduce the figure, but perhaps change slightly the settings of the display software (for example, to view a surface from a different 3-d perspective), one would simply edit the code in the window and re-run the code; the figure would be re-computed and re-displayed.

# SPM & Reproducible Research

**DEM\_demo**

Generalised filtering, Active inference and Free-energy

Overview

PDF Matlab code Run demo

Static Models

- General Linear Model
- Factor Analysis
- Empirical Bayes
- Figure-ground
- Sparse regression
- PEB with BMR

Variational Filtering

- Linear deconvolution
- Double-well

Generalised Filtering

- Triple estimation
- Phase-space reduction
- Hemodynamics
- Cubature filtering

Perceptual learning and inference

- Bird-songs and priors
- Mismatch negativity
- Categorisation
- Position invariance
- Omission responses
- Face recognition

Cognitive neuroscience (continuous states)

- Biased competition
- Action-observation
- Cornsweet illusion
- Slow pursuit
- MMN and latency
- Visual search
- Visual occlusion
- Oculomotor delays
- Sensory attenuation
- Evidence accumulation

Self-organisation and dynamics

- Life as we know it
- Loss and surprise
- Criticality and slowing
- Learning and entropy
- Synaptic selection
- A physics of life

Dynamic Models

- Ornstein-Uhlenbeck
- Bayesian filtering
- Linear deconvolution
- Lorenz attractor
- Dual estimation
- Double-well
- Triple estimation
- Contact lens
- DEM and Kalman filtering
- Image deconvolution

Variational Laplace and dynamic causal modelling

- Stochastic DCM for fMRI
- Large DCM for fMRI
- Spectral DCM for fMRI
- Empirical Bayes for DCM
- Eigenmodes and DCM
- Bayesian model reduction

Active inference

- Attractor dynamics
- Mountain car
- Visual tracking
- Reaching
- Motor trajectories
- Writing

Behaviour and learning (dynamic)

- Addiction and SHC
- Cost and divergence
- Heteroclinic channels
- Affordance and cues
- Agency and MDP
- Eyeblink conditioning

Behaviour and learning (discrete)

- Waiting game
- Urn or beads task
- Trust games
- Epistemic value
- Habit learning
- Visual foraging
- Reading
- Rule learning
- Mixed models
- Maze learning
- Evidence accumulation

Hierarchical (empirical) Bayes

- General Linear Model
- Bayes factors
- PEB group inversion
- Lindley paradox
- Simulated EEG analysis
- PEB & grand averages
- PEB & session effects

Communication and multiagent games

- Birdsong duet
- Morphogenesis

Behavioural modelling

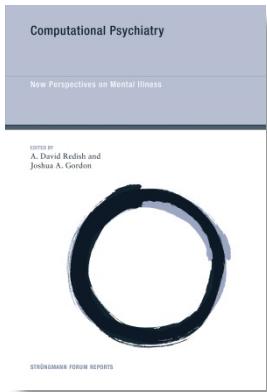
- Meta-modelling
- Nosology
- Choice modeling

Physiological models

- Hemodynamics

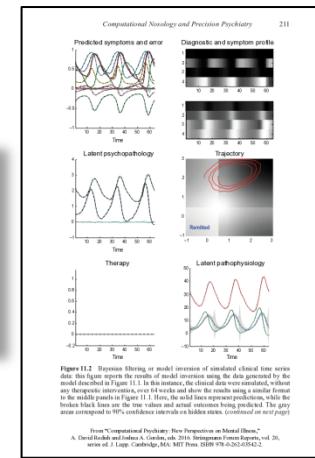
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# SPM & Reproducible Research



## Computational Nosology and Precision Psychiatry A Proof of Concept

Karl J. Friston



**Generalised filtering, Active inference and Free-energy**

[PDF](#) [Matlab code](#) [Run demo](#)

**Static Models**

- [General Linear Model](#)
- [Factor Analysis](#)
- [Empirical Bayes](#)
- [Figure-ground](#)
- [Sparse regression](#)
- [PEB with BNP](#)

**Dynamic Models**

- [Ornstein-Uhlenbeck](#)
- [Bayesian Inference](#)
- [Linear deconvolution](#)
- [Lorenz attractor](#)
- [Dual estimation](#)
- [Double-well](#)
- [DEB and Kalman filtering](#)
- [Image deconvolution](#)

**Variational Filtering**

- [Linear deconvolution](#)
- [Double-well](#)

**Generalized Inference**

- [Triple estimation](#)
- [Phase-space reduction](#)
- [Cubature filtering](#)

**Perceptual learning and inference**

- [Bird-song and priors](#)
- [Mismatch negativity](#)
- [Category](#)
- [Position invariance](#)
- [Omission responses](#)
- [Face recognizer](#)

**Active Inference**

- [Attractor dynamics](#)
- [Mountain car](#)
- [Reaching](#)
- [Writing](#)
- [Motor trajectories](#)

**Behavioural modelling**

- [Meta-modelling](#)
- [Hesiology](#)
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- [Hemodynamics](#)

**Cognitive neuroscience (continuous states)**

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**Behaviour and learning (dynamic)**

- [Addiction and SNC](#)
- [Cost and divergence](#)
- [Heteroclinic channels](#)
- [Affordance and cues](#)
- [Agency and MOP](#)
- [Eyeblink conditioning](#)

**Behaviour and learning (discrete)**

- [Walking game](#)
- [Urn or beads task](#)
- [Trust games](#)
- [Epistemic value](#)
- [Visual foraging](#)
- [Habit learning](#)
- [Rule learning](#)
- [Mixed models](#)
- [Maze learning](#)
- [Evidence accumulation](#)

**Self-organisation and dynamics**

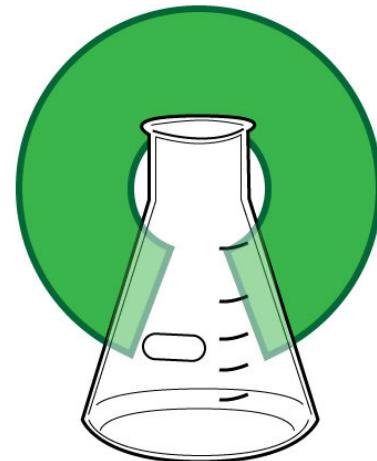
- [Life as we know it](#)
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- [A physics of life](#)

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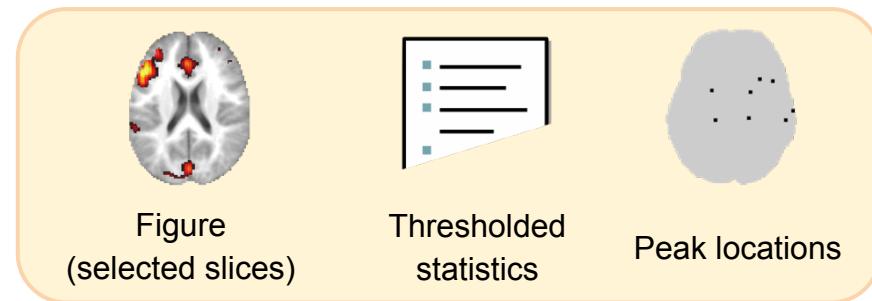
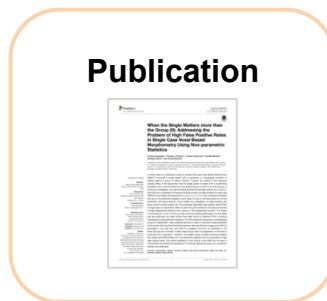
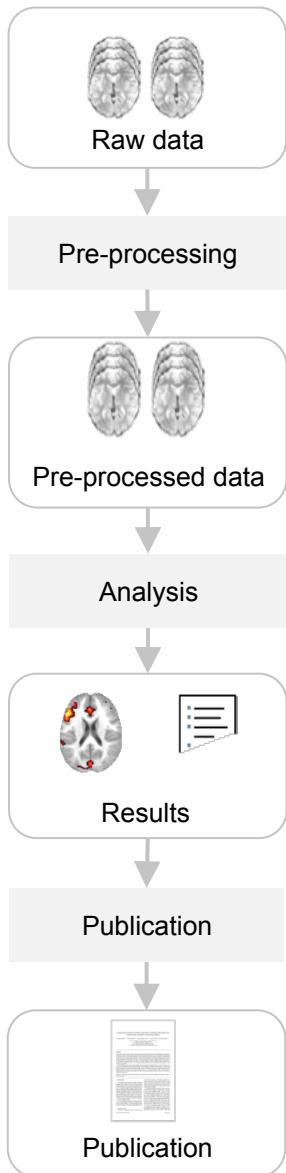
27 % Karl J. Friston
28 % 1st DEM_demo_ontology.m 6511 2015-08-02 15:05:41Z karl $ 
29 %
30 % Set up the generative model
31 %*****%
32 rng('default')
33 N = 100;
34 % length of trajectory
35 S = 10;
36 %-----%
37 N = 100;
38 % serial correlations and other inversion parameters
39 %-----%
40 M(1).E.s = 1/2;
41 M(1).E.K = 1/2;
42 M(1).E.N = 1/16;
43 M(1).E.M = 32;
44 M(1).E.U = 0.5;
45 M(1).U = 0.5;
46 % therapeutic intervention: ranging between zero and one, starting halfway
47 % through the patient assessment
48 U = spm_phi((1:N) - N/2);
49 U = U + 0.1;
50 U = spm_phi((1:N) - N/2);
51 % level 1: the level that generates diagnostic and symptom profiles g(v) from
52 % states (x) that are subject to interventions (U)
53 %-----%
54 P_A = randn(6,2)/32;
55 P_B = [0 0 1 1 0 1];
56 P_C = [1 0 0 0 0 0];
57 P_D = [0 0 0 1 0 1];
58 P_E = [0 0 0 0 1 0];
59 P_F = [0 0 0 0 0 1];
60 P_G = exp(12);
61 %-----%
62 % level 2: the level that generates latent causes v = g(x) from (pathophysiological)
63 % states (x) that are subject to interventions (U)
64 %-----%
65 P_A = [10 24 1];
66 P_B = [2 0; 1/2 1];
67 P_C = [0 0 0 0 0 0];
68 P_D = [0 0 0 0 0 0];
69 P_E = [0 0 0 0 0 0];
70 P_F = [0 0 0 0 0 0];
71 P_G = [2; 4; 32];
72 P_H = diag([1 1 0 0 0 0 0]);
73 P_I = diag([0 0 0 0 0 0 0]);
74 P_J = exp(8);
75 P_K = exp(4);
76 P_L = exp(1);
77 P_M = U(:,1);
78 P_N = exp(16);
79 %-----%
80 % level 3: the exogenous (therapeutic) intervention
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89 M(2).F = @(x,v,P){P.A(1)*P.A(1)'*((1 - v'*P.B)*P.C*P.D*(P.E*(P.F*(P.G*x))))/16};
90 M(2).G = @(x,v,P){P.A(1)*P.A(1)'*((1 - v'*P.B)*P.C*P.D*(P.E*(P.F*(P.G*x))))/16};
91 M(2).X = [2; 4; 32];
92 M(2).P_E = diag([1 1 0 0 0 0]);
93 M(2).P_F = diag([0 0 0 0 0 0]);
94 M(2).P_G = diag([1 1 0 0 0 0]);
95 M(2).V = exp(8);
96 M(2).W = exp(4);
97 M(2).U = U(:,1);
98 M(2).Y = exp(16);
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# Open Science

- Open Methodology
- Open Source
- Open Data
- Open Access
- Open Peer Review
- Open Educational Resources



# Neuroimaging publications



- ✓ Reporting guidelines: COBIDAS
- ✗ Incomplete statistical results
- ✗ Ambiguous/incomplete methods
- ✗ Metadata is not machine readable

# International Collaborative Effort

- ❑ INCF Neuroimaging data sharing Task Force  
(NIDASH)



- Representing 13 labs
- Weekly teleconferences, focused workshops, GitHub
- Open

- ❑ Stanford Center for Reproducible Neuroscience
- ❑ ReproNim

<http://nidm.nidash.org>

<http://reproducibility.stanford.edu>

<http://www.reproducibleimaging.org>

# Brain Imaging Data Structure

# NeuroImaging Data Model

# Brain Imaging Data Structure (BIDS)

*“A simple and intuitive way to organise and describe your neuroimaging and behavioural data.”*

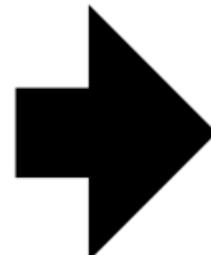
Benefits of a common standard:

- ❑ Minimised curation
  - Within a lab over time
  - Between labs (collaboration and multi-centre studies)
  - Between public databases (e.g. OpenfMRI)
- ❑ Error reduction (automated validation)
- ❑ Optimised usage of data analysis software  
(completely automated analysis workflows)

# Brain Imaging Data Structure (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
  - 1208200617178\_22\_9967.dcm
  - 1208200617178\_22\_3894.dcm
  - 1208200617178\_22\_3899.dcm
- 1208200617178\_23/
- 1208200617178\_24/
- 1208200617178\_25/



my\_dataset/

- participants.tsv
- sub-01/
  - anat/
    - sub-01\_T1w.nii
  - func/
    - sub-01\_task-rest\_bold.nii
    - sub-01\_task-rest\_bold.json
  - dwi/
    - sub-01\_dwi.nii
    - sub-01\_dwi.json
    - sub-01\_dwi.bval
    - sub-01\_dwi.bvec
- sub-02/
- sub-03/
- sub-04/

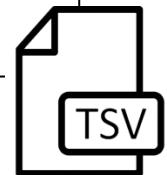
<http://bids.neuroimaging.io/>

# Brain Imaging Data Structure (BIDS)

```
my_dataset/
  participants.tsv
  sub-01/
    anat/
      sub-01_T1w.nii
    func/
      sub-01_task-rest_bold.nii
      sub-01_task-rest_bold.json
    dwi/
      sub-01_dwi.nii
      sub-01_dwi.json
      sub-01_dwi.bval
      sub-01_dwi.bvec
  sub-02/
  sub-03/
  sub-04/
```



participant_id	age	sex
Sub-001	34	M
Sub-002	22	F
Sub-003	33	F



# Brain Imaging Data Structure (BIDS)

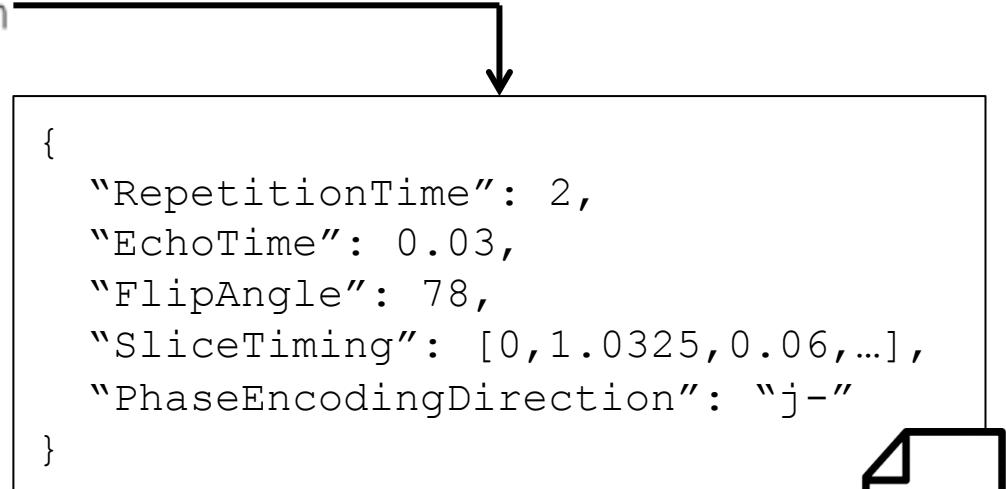
```
my_dataset/
  participants.tsv
  sub-01/
    anat/
      sub-01_T1w.nii
    func/
      sub-01_task-rest_bold.nii
      sub-01_task-rest_bold.json
    dwi/
      sub-01_dwi.nii
      sub-01_dwi.json
      sub-01_dwi.bval
      sub-01_dwi.bvec
  sub-02/
  sub-03/
  sub-04/
```



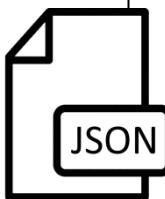
NIfTI

# Brain Imaging Data Structure (BIDS)

```
my_dataset/
  participants.tsv
  sub-01/
    anat/
      sub-01_T1w.nii
    func/
      sub-01_task-rest_bold.nii
      sub-01_task-rest_bold.json
    dwi/
      sub-01_dwi.nii
      sub-01_dwi.json
      sub-01_dwi.bval
      sub-01_dwi.bvec
  sub-02/
  sub-03/
  sub-04/
```



```
{  
  "RepetitionTime": 2,  
  "EchoTime": 0.03,  
  "FlipAngle": 78,  
  "SliceTiming": [0,1.0325,0.06,...],  
  "PhaseEncodingDirection": "j-"  
}
```



# BIDS Validator

<http://incf.github.io/bids-validator/>

## 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.

[view 1 error in 23 files](#)

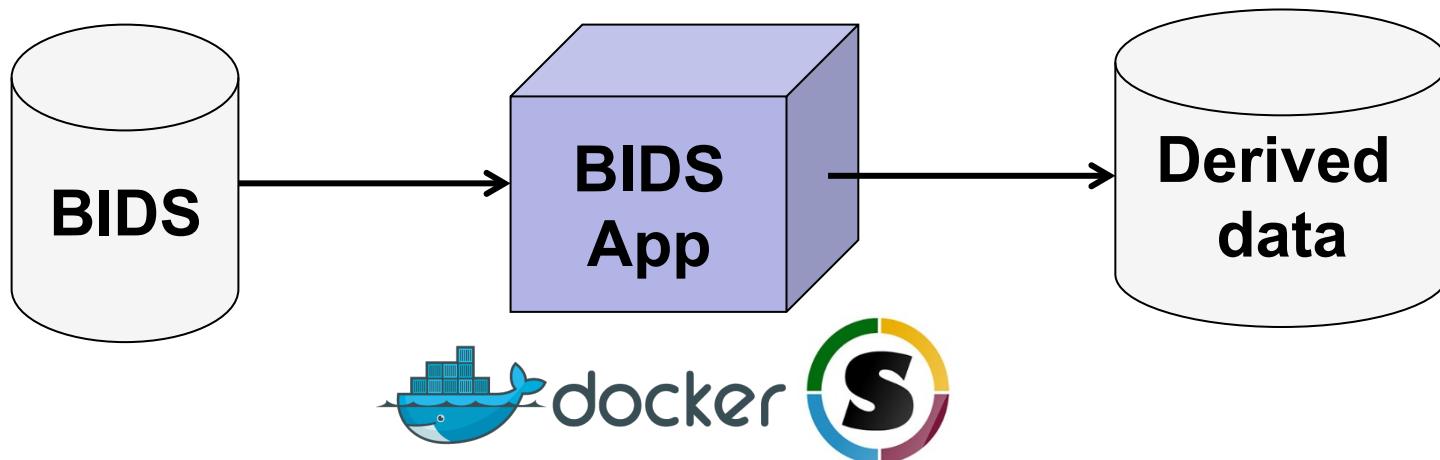
[view 1 warning in 4 files](#)

# BIDS Extensions

## ❑ Work in progress:

- PET / SPECT
- EEG / MEG
- Model and hypothesis specifications
- ...

# BIDS Apps



```
docker run ... bids/spm /bids /output participant --participant_label 01  
docker run ... bids/spm /bids /output group
```

<http://bids-apps.neuroimaging.io/>

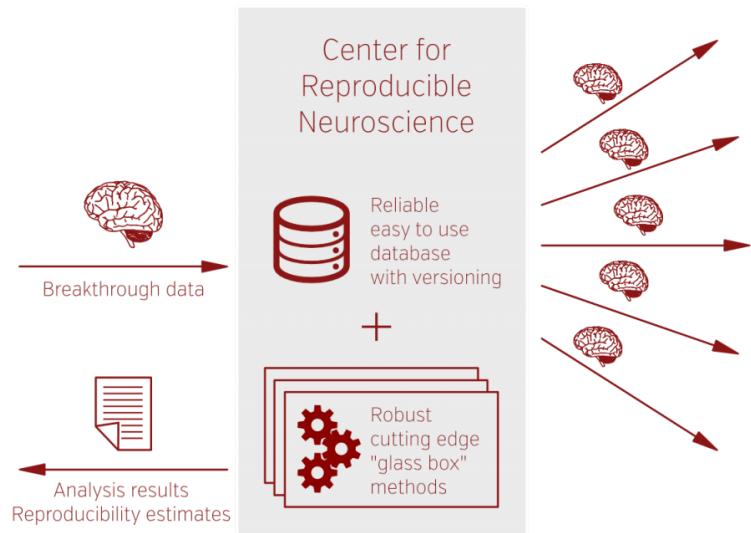
<https://www.docker.com/>

<http://singularity.lbl.gov/>

K.J. Gorgolewski et al. BIDS Apps: improving ease of use, accessibility, and reproducibility of neuroimaging data analysis methods. *PLOS Computational Biology* (2017)

# Available BIDS Apps

bids/example	version 0.0.6	issues 0	build passing
bids/freesurfer	version v6.0.0-2	issues 0	build passing
bids/ndmrg	version v0.0.46	issues 0	build passing
bids/BROCCOLI	version v1.0.0	issues 0	build passing
bids/FibreDensityAndCrosssection	version v0.0.1	issues 0	build passing
bids/SPM	version v0.0.5	issues 0	build passing
bids/MRIQC	version 0.0.2	issues 0	build Project not found
bids/QAP	Image not found	issues 0	build passing
bids/CPAC	version v1.0.1a_13	issues 0	build passing
bids/hyperalignment	Image not found	issues 0	build passing
bids/mindboggle	version 0.0.1	issues 2	build failed
bids/MRtrix3_connectome	version latest	issues 0	build passing
bids/rs_signal_extract	version 0.1	issues 0	build passing
bids/aa	version enh_vario...	issues 0	build passing
bids/niak	version latest	issues 3	build passing
bids/oppni	version latest	issues 0	build passing
bids/fmriprep	version 0.2.0	issues 0	build passing
bids/brainiak-srm	version latest	issues 0	build passing
bids/nipypipelines	Image not found	issues 0	build passing
bids/HCPPipelines	version v3.17.0-13	issues 0	build passing
bids/MAGeTbrain	Image not found	issues 0	build timedout
bids/tracula	version v6.0.0-2	issues 0	build passing



Providing access to state of the art methods while incentivizing data sharing

<http://bids-apps.neuroimaging.io/>

# Brain Imaging Data Structure

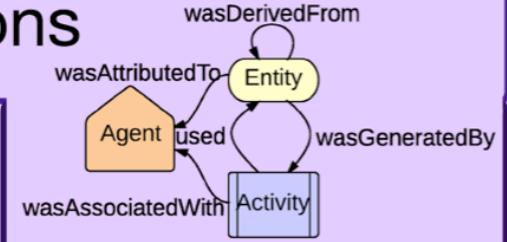
# NeuroImaging Data Model

# NIDM: a set of specifications to describe neuroimaging data



## NIDM Core Vocabulary

## PROV Family of Specifications



# NIDM: a set of specifications to describe neuroimaging data

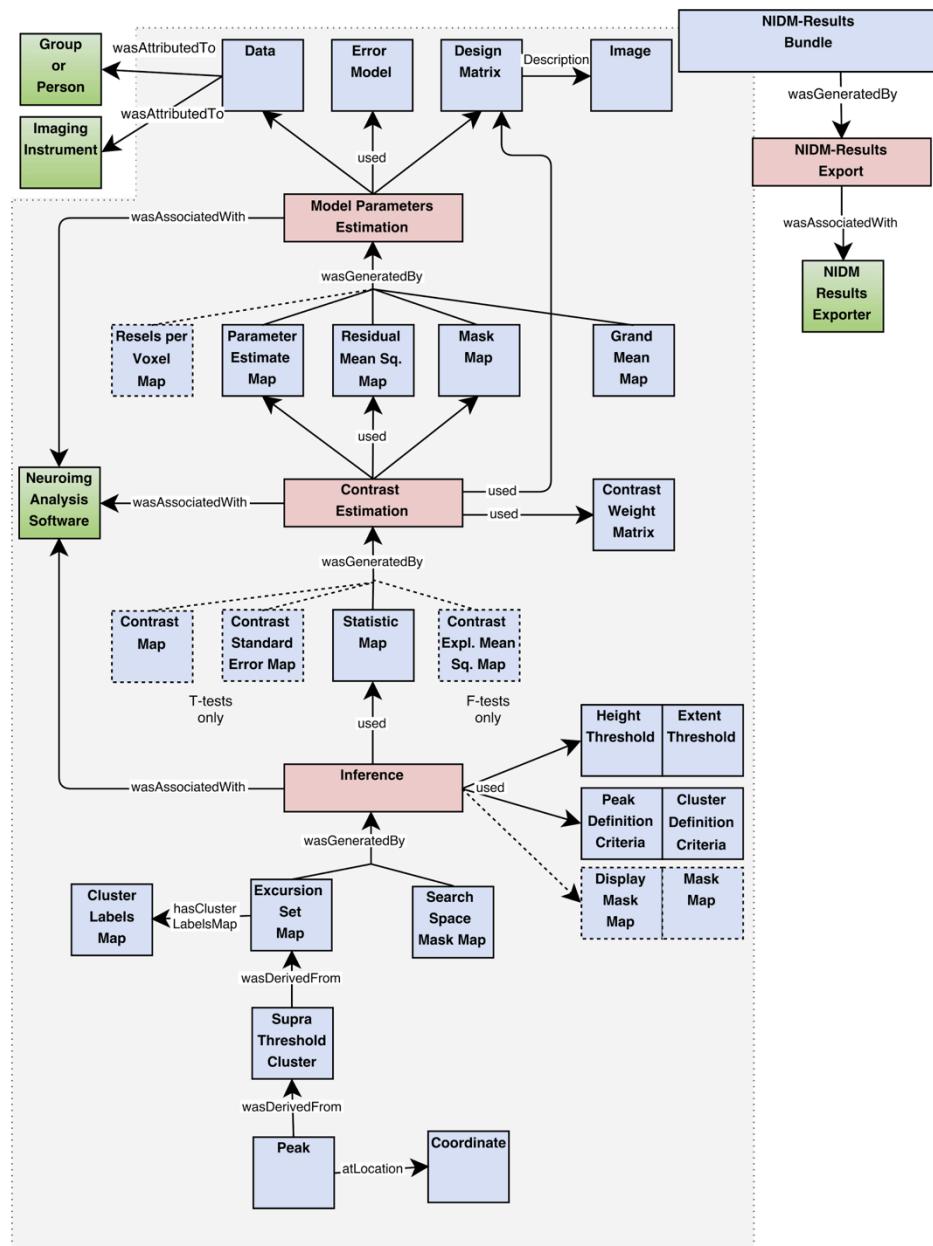


## NIDM Core Vocabulary

## PROV Family of Specifications



## NIDM-Results



**Statistics:** *p*-values adjusted for search volume

set-level		cluster-level				peak-level					mm mm mm		
p	c	$p_{\text{FWE-corr}}$	$q_{\text{FDR-corr}}$	$k_E$	$p_{\text{uncorr}}$	$p_{\text{FWE-corr}}$	$q_{\text{FDR-corr}}$	T	$(Z_{\equiv})$	$p_{\text{uncorr}}$	$\beta_1$	$\beta_2$	$\beta_3$
0.000	12	0.000	0.000	425	0.000	0.000	0.000	17.09	Inf	0.000	57	-22	11
						0.000	0.000	14.42	Inf	0.000	66	-10	-1
						0.000	0.000	10.89	Inf	0.000	69	-19	11
		0.000	0.000	568	0.000	0.000	0.000	15.94	Inf	0.000	-63	-28	14
						0.000	0.000	14.68	Inf	0.000	-48	-34	14
	31					0.000	0.000	13.23	Inf	0.000	-66	-10	2
		0.000	0.000	31	0.000	0.000	0.003	7.03	6.12	0.000	36	-28	-13
		0.000	0.001	12	0.000	0.000	0.004	6.90	6.03	0.000	54	-1	44
		0.003	0.096	3	0.048	0.002	0.075	6.07	5.44	0.000	-63	-55	-7
		0.000	0.003	10	0.001	0.006	0.207	5.77	5.22	0.000	-33	-31	-19

table shows 3 local maxima more than 8.0mm apart

Height threshold: T = 5.25, p = 0.000 (0.050)

Extent threshold: k = 0 voxels

Expected voxels per cluster,  $\langle k \rangle = 0.753$

Expected number of clusters,  $\langle c \rangle = 0.07$

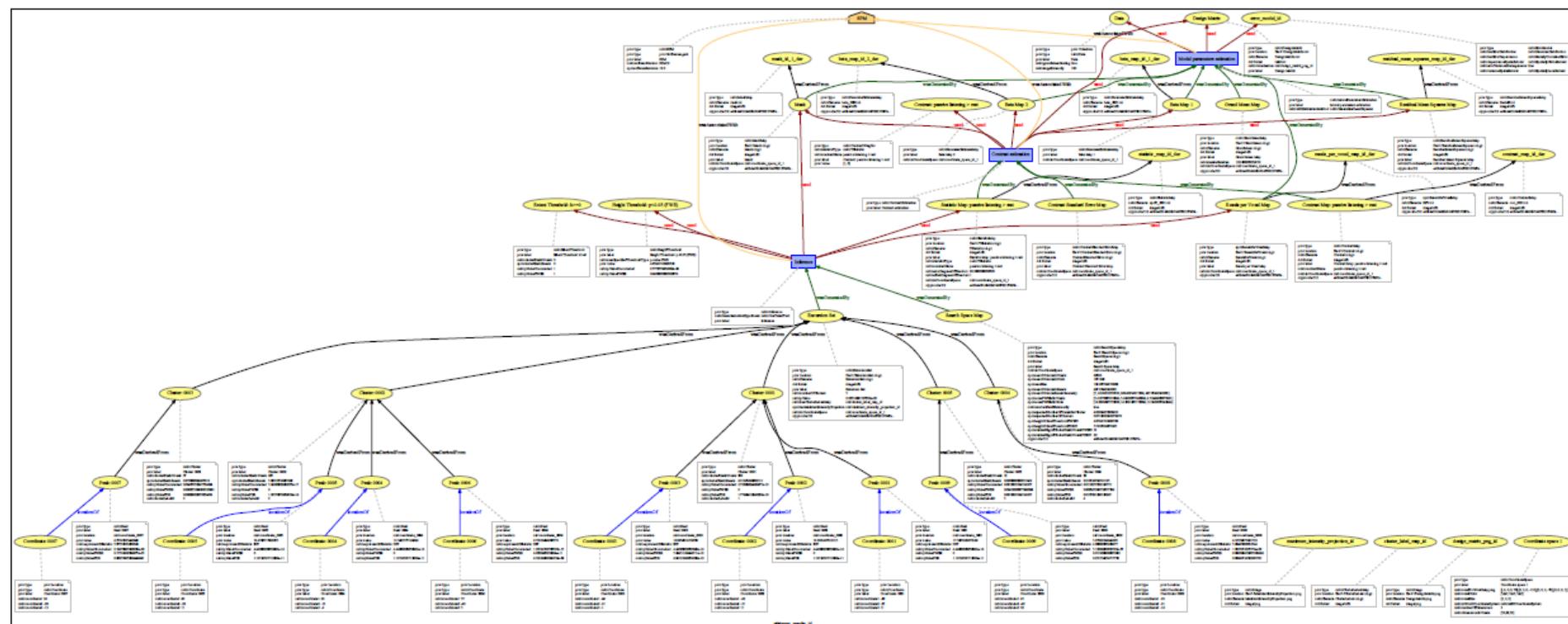
FWEp: 5.253, FDRp: 6.320, FWEc: 1, FDRc: 10

Degrees of freedom = [1.0, 73.0]

FWHM = 9.9 9.9 8.6 mm mm mm; 3.3 3.3 2.9 {voxels}

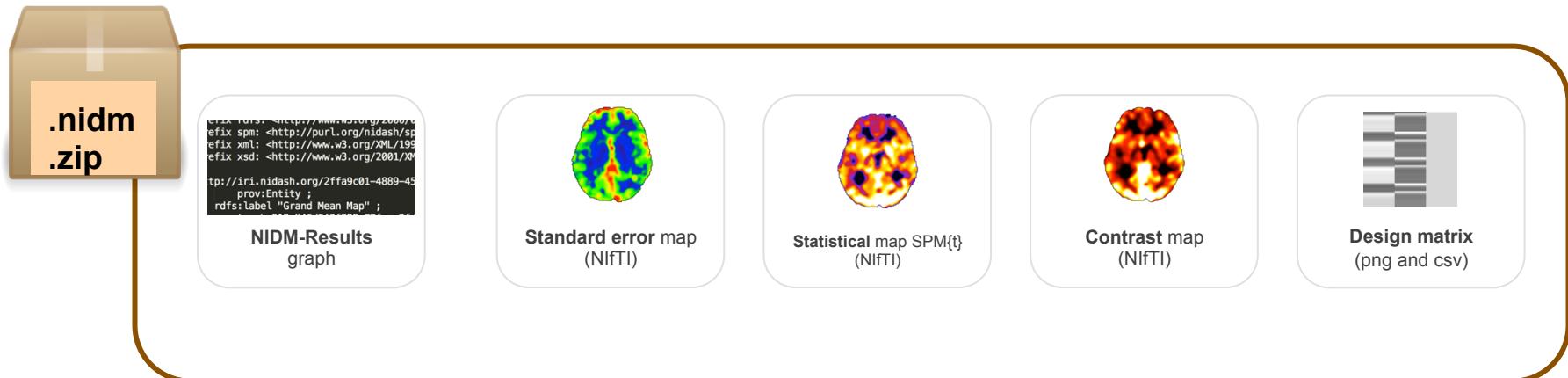
Volume: 1901367 = 70421 voxels = 1995.7 resels

Voxel size: 3.0 3.0 3.0 mm mm mm; (resel = 31.52 voxels)



# NIDM-Results

**NIDM-Results pack:** Compressed file containing a NIDM-Results serialisation and some or all of the referenced image data files.



C. Maumet et al. Sharing brain mapping statistical results with the neuroimaging data model. *Scientific Data* (2017). Slide: C. M.

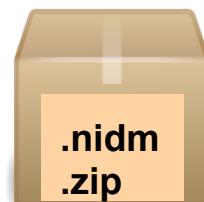
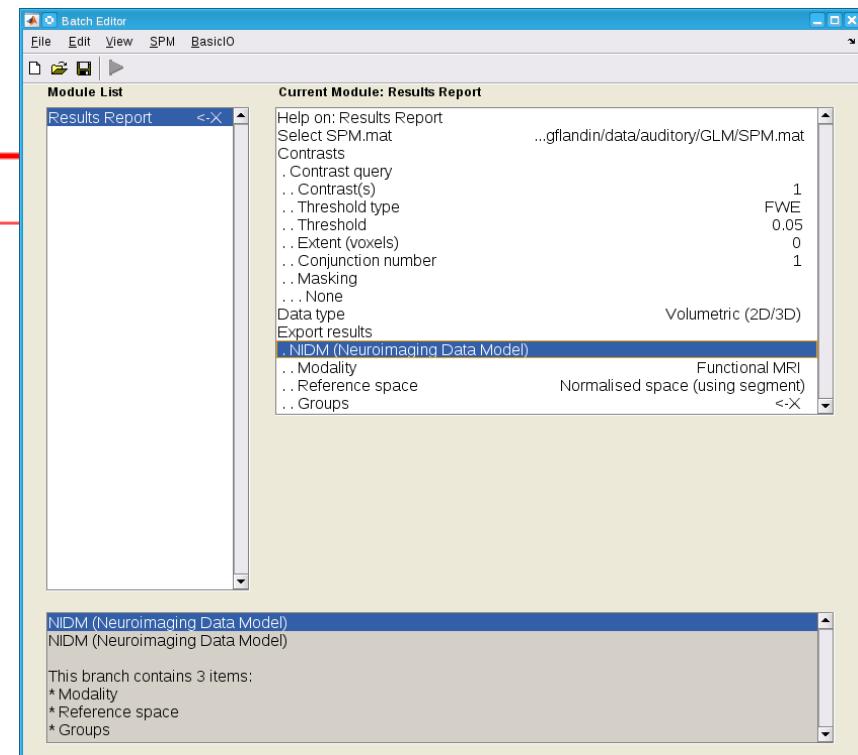
Slide: C. Maumet

# SPM export to NIDM-Results

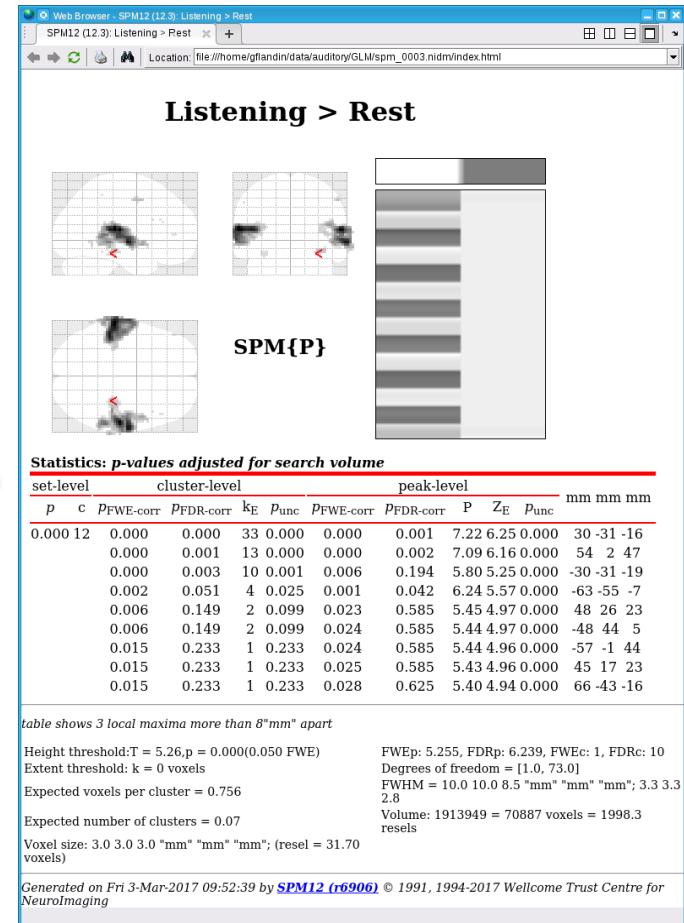
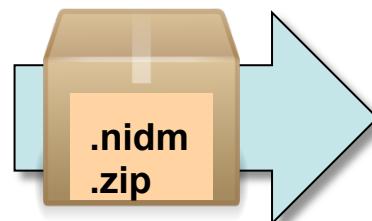
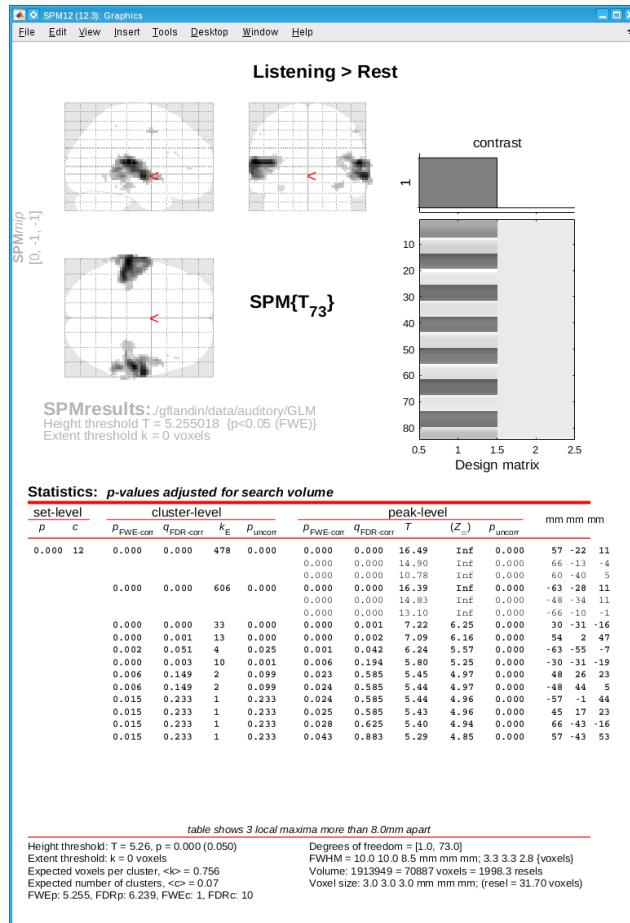
**Statistics: p-values adjusted for search volume**

set-level		cluster-level			peak-level					
p	c	$p_{FWE\text{-corr}}$	$q_{FDR\text{-corr}}$	$k_E$	$p_{uncorr}$	$p_{FWE\text{-corr}}$	$q_{FDR\text{-corr}}$	T	( $Z_{\equiv}$ )	$p_{uncorr}$
0.000	12	0.000	0.000	478	0.000	0.000	0.000	16.49	Inf	0.000
						0.000	0.000	14.90	Inf	0.000
						0.000	0.000	10.78	Inf	0.000
						0.000	0.000	14.83	Inf	0.000
						0.000	0.000	13.10	Inf	0.000
						0.000	0.001	7.22	6.25	0.000
						0.000	0.002	7.09	6.16	0.000
						0.001	0.042	6.24	5.57	0.000
						0.006	0.194	5.80	5.25	0.000
						0.023	0.585	5.45	4.97	0.000
						0.024	0.585	5.44	4.97	0.000
						0.024	0.585	5.44	4.96	0.000
						0.025	0.585	5.43	4.96	0.000
		Print text table				0.028	0.625	5.40	4.94	0.000
		Extract table data structure				0.043	0.883	5.29	4.85	0.000
		Export to CSV file								
		Export to NIDM-Results								

Locally   
Upload to NeuroVault



# NIDM-Results Viewer



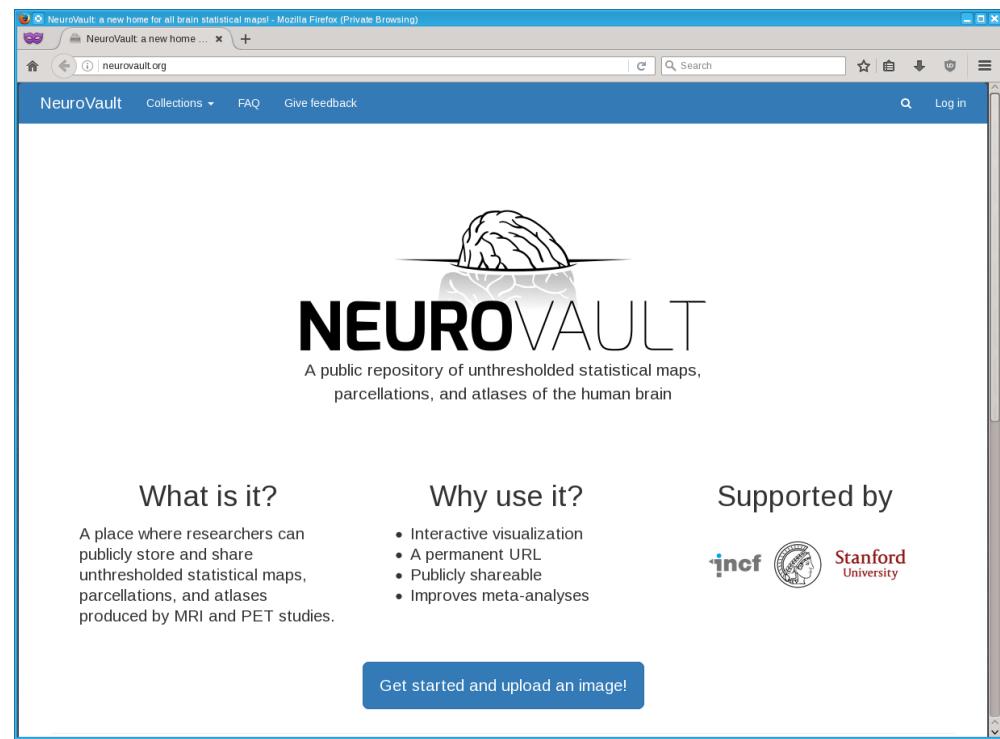
Thomas Maullin-Sapey & Camille Maumet

<https://github.com/ncf-nidash/nidmresults-spmhtml>

# Upload NIDM-Results to NeuroVault

*p*-values adjusted for search volume

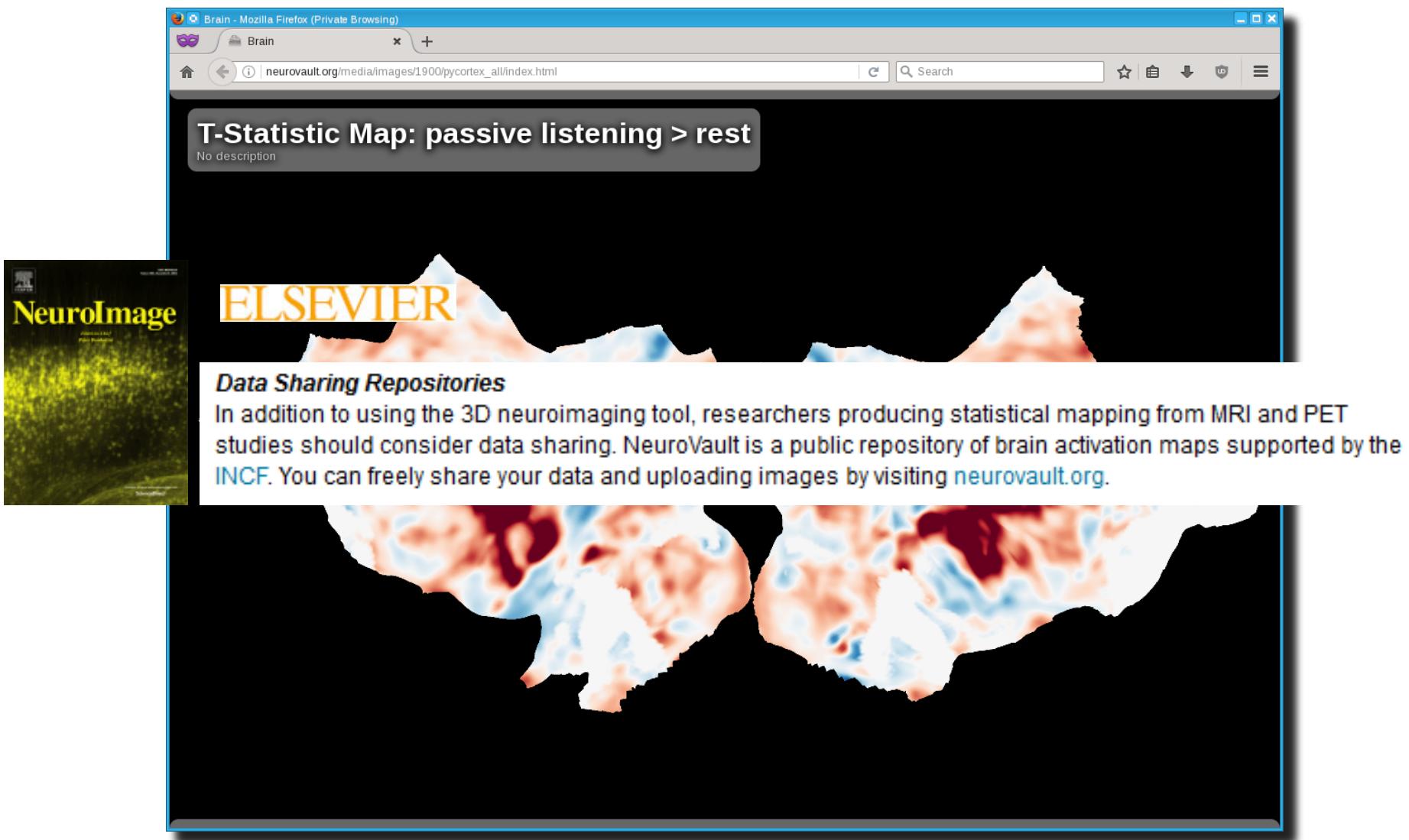
cluster-level				peak-level			
$p_{\text{FWE-corr}}$	$q_{\text{FDR-corr}}$	$k_E$	$p_{\text{uncorr}}$	$p_{\text{FWE-corr}}$	$q_{\text{FDR-corr}}$	$T$	( $Z_{\equiv}$ )
0.000	0.000	478	0.000	0.000	0.000	16.49	Inf
				0.000	0.000	14.90	Inf
				0.000	0.000	10.78	Inf
0.000	0.000	606	0.000	0.000	0.000	16.39	Inf
				0.000	0.000	14.83	Inf
				0.000	0.000	13.10	Inf
0.000	0.000	33	0.000	0.000	0.001	7.22	6.25
0.000	0.001	13	0.000	0.000	0.002	7.09	6.16
0.002	0.051	4	0.025	0.001	0.042	6.24	5.57
0.000	0.003	10	0.001	0.006	0.194	5.80	5.25
0.006	0.149	2	0.099	0.023	0.585	5.45	4.97
0.006	0.149	2	0.099	0.024	0.585	5.44	4.97
0.015	0.233	1	0.233	0.024	0.585	5.44	4.96
Print text table				3	0.025	0.585	5.43
Extract table data structure				3	0.028	0.625	5.40
Export to CSV file				3	0.043	0.883	5.29
Export to NIDM-Results				Locally Upload to NeuroVault			



The screenshot shows the NeuroVault homepage. At the top, there's a navigation bar with links for 'NeuroVault', 'Collections', 'FAQ', and 'Give feedback'. On the right, there's a 'Log in' button. Below the navigation is a logo featuring a stylized brain and the text 'NEUROVAULT'. A subtext below the logo reads: 'A public repository of unthresholded statistical maps, parcellations, and atlases of the human brain'. To the left of the main content area, there's a sidebar with sections for 'What is it?' and 'Why use it?'. The 'What is it?' section describes NeuroVault as a place where researchers can store and share statistical maps, parcellations, and atlases. The 'Why use it?' section lists four benefits: 'Interactive visualization', 'A permanent URL', 'Publicly shareable', and 'Improves meta-analyses'. At the bottom right, there's a blue button labeled 'Get started and upload an image!'. On the far right, there's a 'Supported by' section with logos for INCF and Stanford University.

K.J. Gorgolewski et al. NeuroVault.org: a web-based repository for collecting and sharing unthresholded statistical maps of the human brain. *Frontiers in Neuroinformatics* (2015).

# Upload NIDM-Results to NeuroVault



Brain - Mozilla Firefox (Private Browsing)

neurovault.org/media/images/1900/pycortex\_all/index.html

T-Statistic Map: passive listening > rest

No description

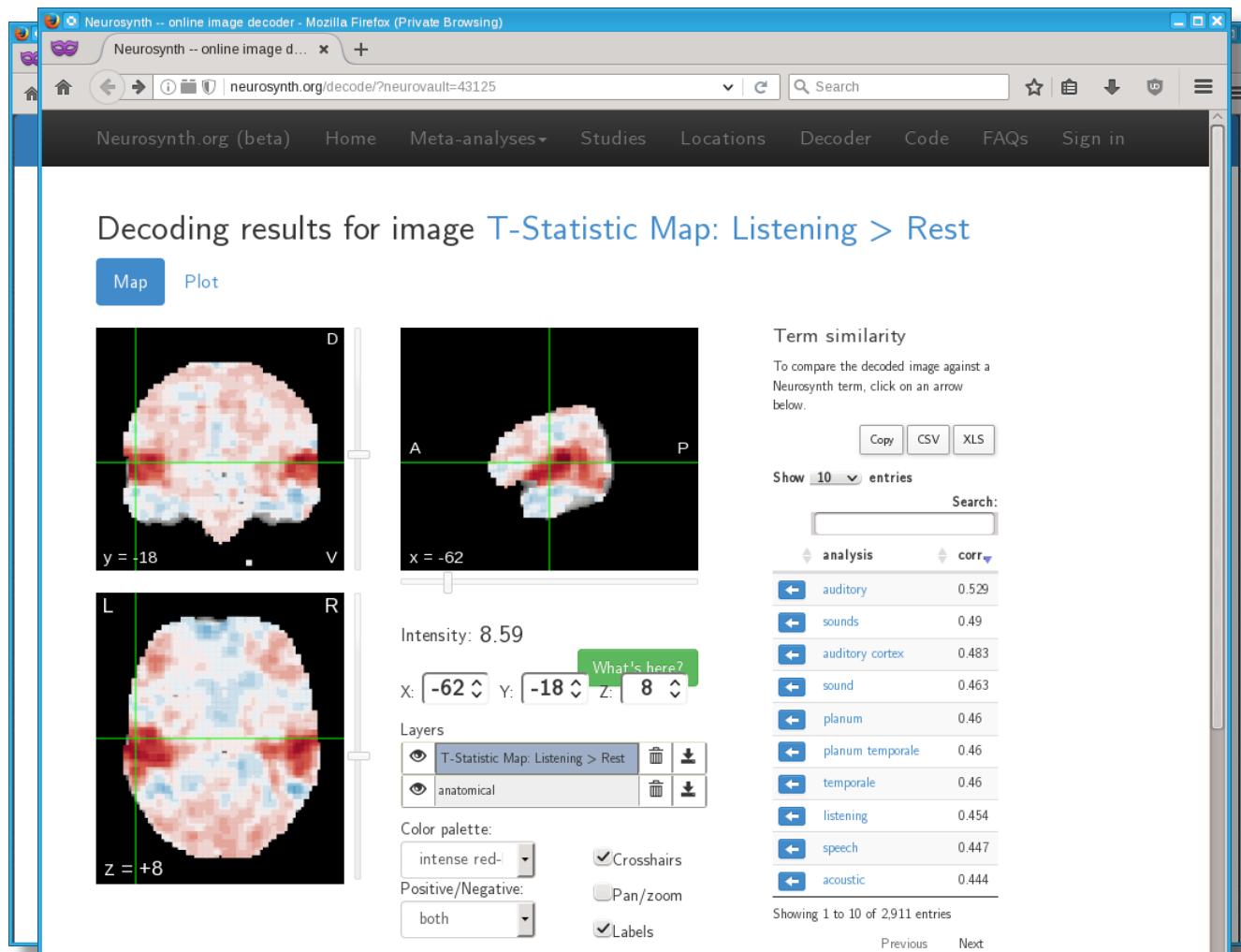
ELSEVIER

**Data Sharing Repositories**

In addition to using the 3D neuroimaging tool, researchers producing statistical mapping from MRI and PET studies should consider data sharing. NeuroVault is a public repository of brain activation maps supported by the INCF. You can freely share your data and uploading images by visiting [neurovault.org](http://neurovault.org).

NeuroImage

# From NeuroVault to Neurosynth



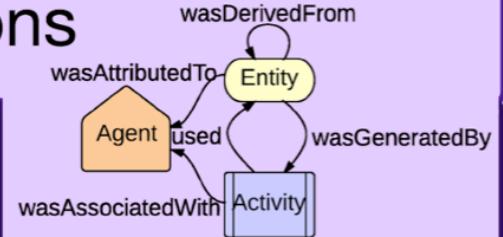
T. Yarkoni et al. Large-scale automated synthesis of human functional neuroimaging data.  
*Nature Methods* (2011)

# NIDM: a set of specifications to describe neuroimaging data



## NIDM Core Vocabulary

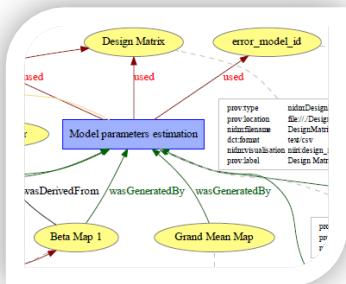
## PROV Family of Specifications



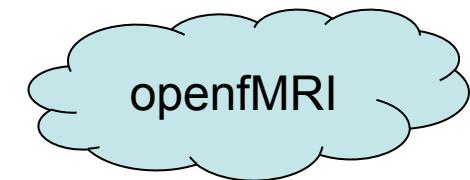
# Conclusion



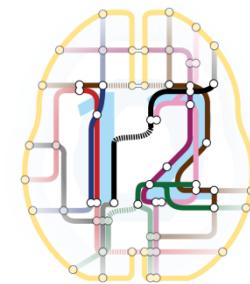
- BIDS
- BIDS Apps



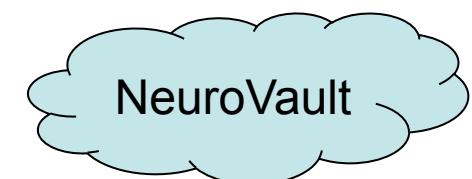
- NIDM-Experiment
- NIDM-Workflow
- NIDM-Results
  - Export
  - Viewer
  - Upload to NeuroVault



`spm_BIDS.m`  
[hub.docker.com/r/bids/spm/](https://hub.docker.com/r/bids/spm/)



`spm_provenance.m`  
`spm_results_nidm.m`  
[github.com/ncf-nidash/nidmresults-spmhtml](https://github.com/ncf-nidash/nidmresults-spmhtml)



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