Combining text mining and coordinate-based meta-analysis

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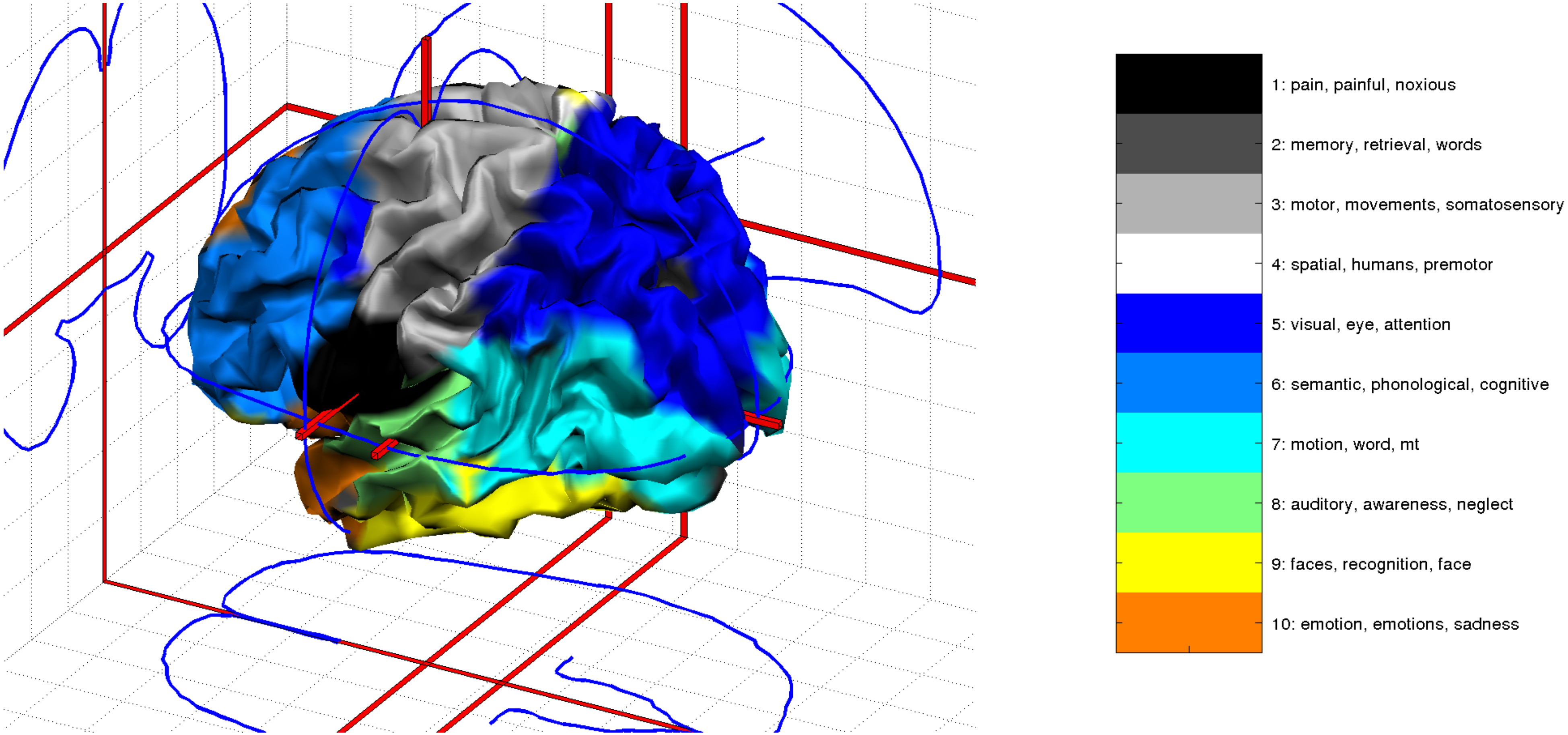
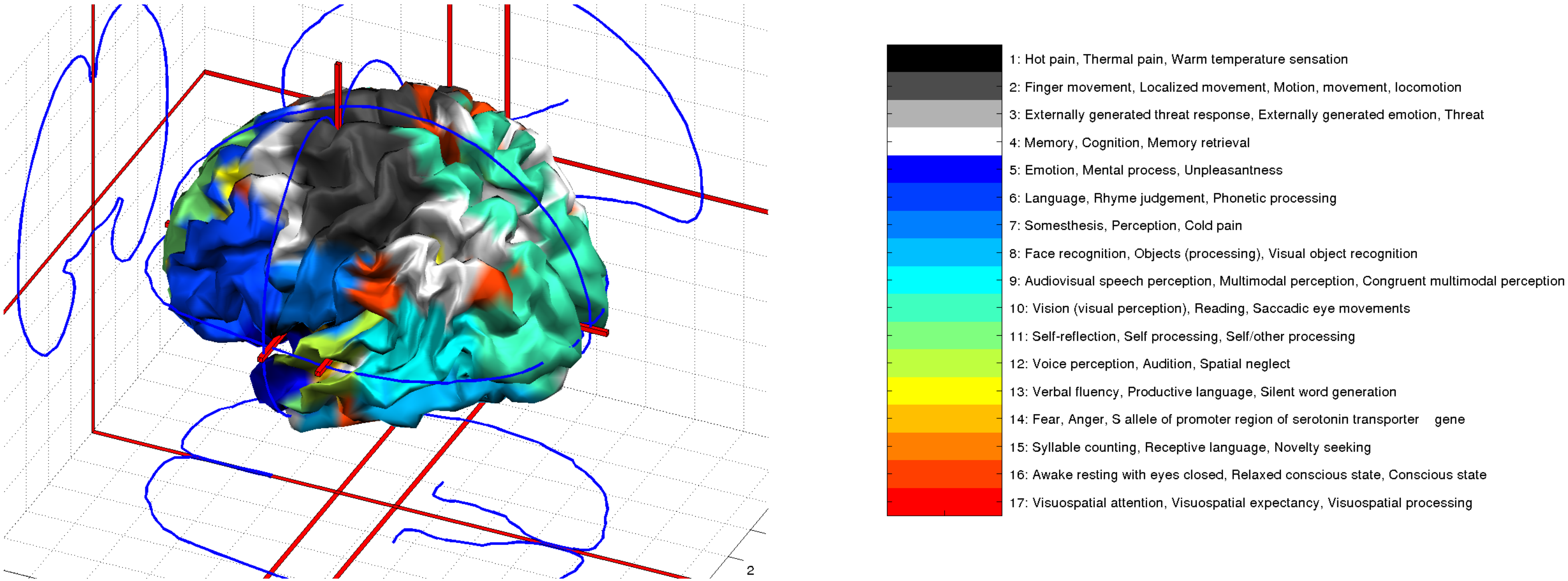
Brain atlas constructed from abstract



Brain atlas constructed from experiment labels



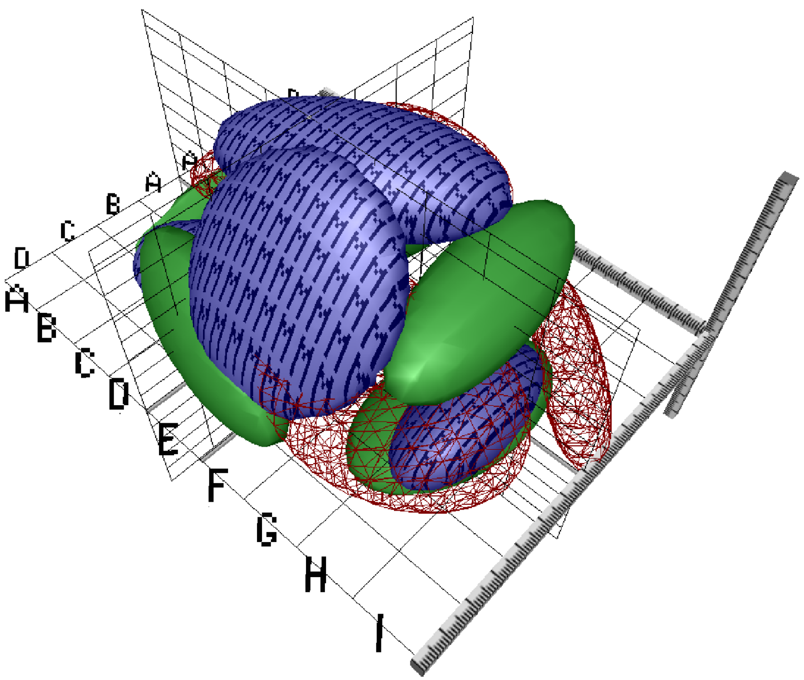
How is this done?

Coordinate-based database

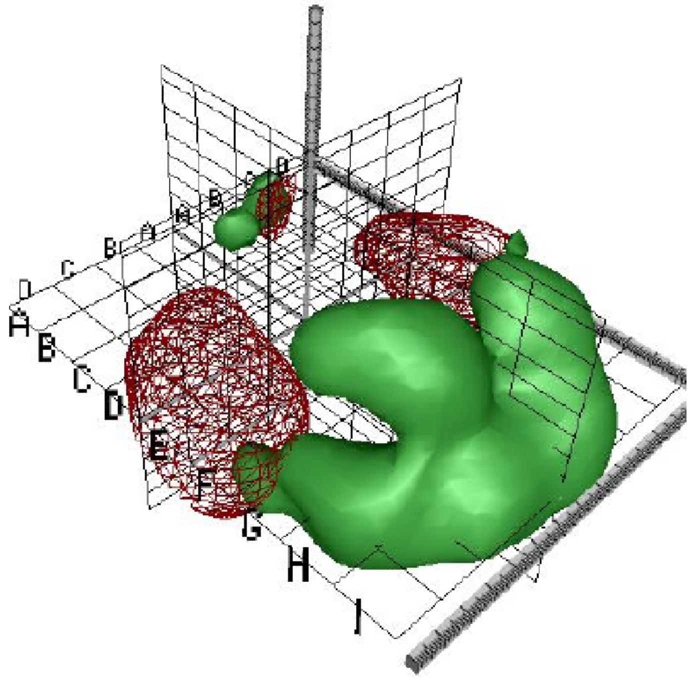
Name	'Old' BrainMap	Brede	Neurosynth
Entry	Manual	Manual	Automatic
Collection	Web scraping	XML	TSV
Papers	224	186	$\approx 10,000$
Experiments	771	586	$> 18,000$
Locations	7,263	3,912	>150,000
Abstracts	✓	✓	✓
Loc. labels	✓	✓	
Exp. labels	✓	✓	
Reference	(Fox and Lancaster, 1994)	(Nielsen, 2003)	(Yarkoni et al., 2011)

Other databases: AMAT (Hamilton, 2009), SumsDB (Van Essen, 2009). Part of Brede Database is in AMAT. 'New' BrainMap.

Modeling of data in BrainMap



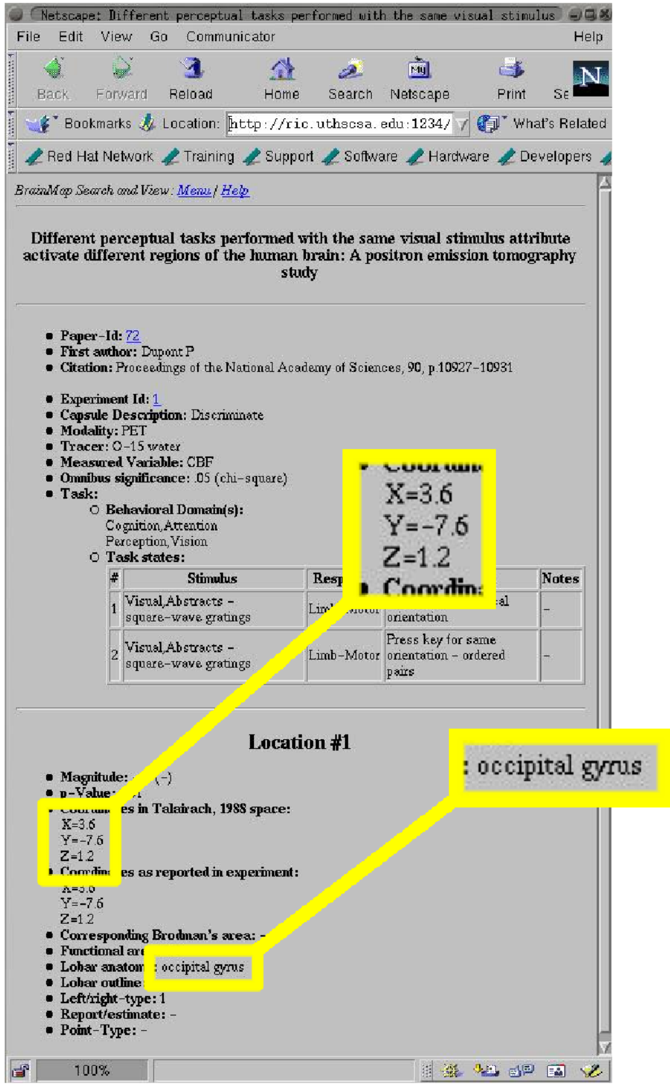
Gaussian mixture model for perception, cognition, motion (Nielsen and Hansen, 1999)



Kernel density estimation for audition, vision (Nielsen and Hansen, 2000)

$p(\mathbf{x}|l)$: $\mathbf{x}$ is Talairach space, l is a BrainMap label ('behavioral domain').

Modeling anatomical labels in BrainMap



"We downloaded 7,263 location web-pages and 3,935 of these locations had an associated anatomical label" (Nielsen and Hansen, 2002b).

$p(\mathbf{x}|l)$: $\mathbf{x}$ is Talairach space, l is the anatomical label (word or phrase) associated with each coordinate, e.g., "occipital gyrus", "gyrus", "occipital".

1,231 word/phrases.

Volume available from: neuro.compute.dtu.dk. as Analyze files: "Meta-analytic region of interest atlas" (Nielsen and Hansen, 2002a).

Modeling anatomical labels in BrainMap

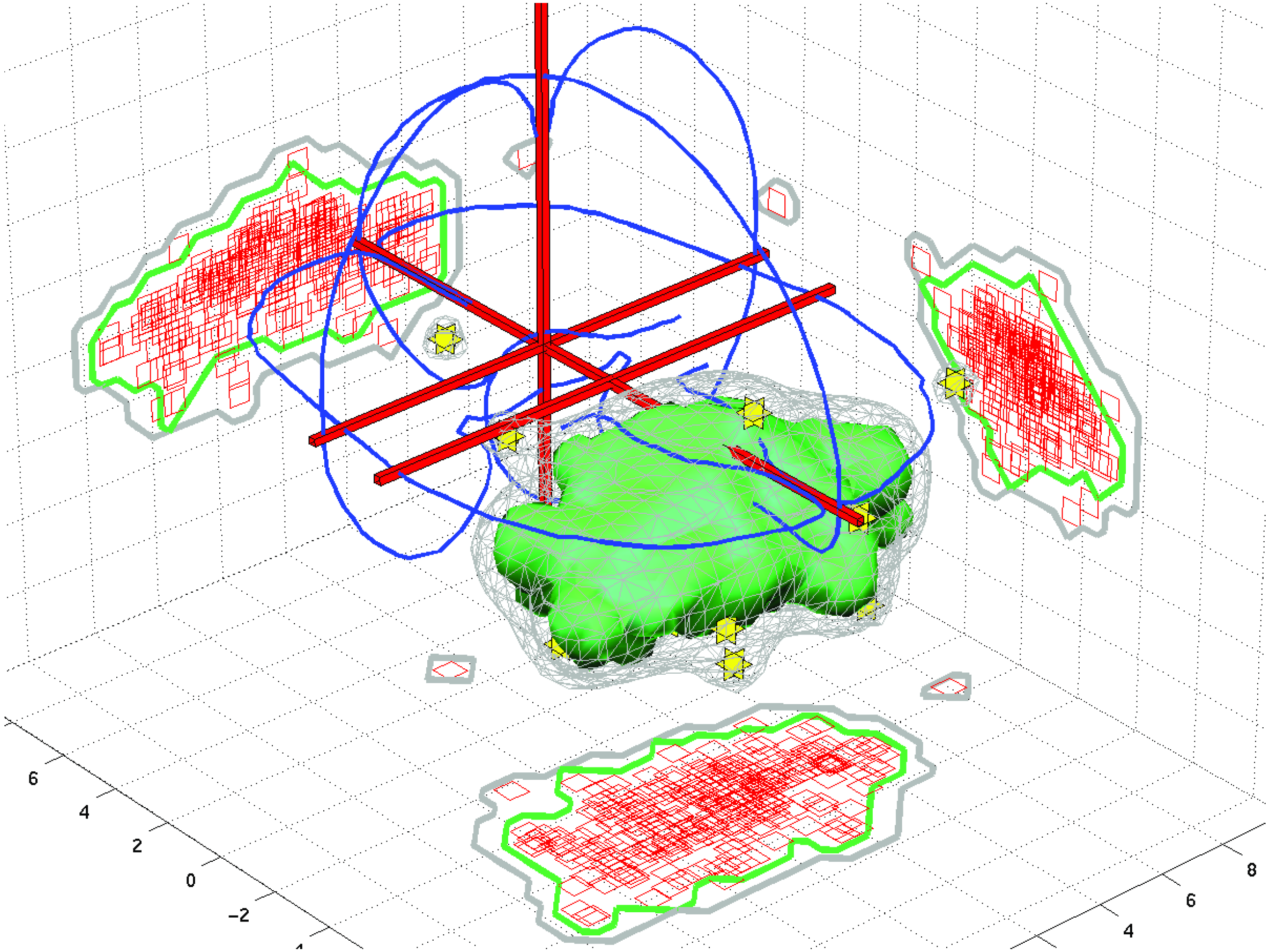
Kernel density estimation with leave-one-out cross-validation for determining the width of the kernel (Nielsen and Hansen, 2002b).

$$E(\sigma^2, l) = -\sum_{n=1}^{N_l} \log p_{-n}(\mathbf{x}_n|\sigma^2, l)$$

$$p_{-n}(\mathbf{x}|\sigma^2, l) = \frac{1}{N_l - 1} \sum_{n' \neq n}^{N_l} (2\pi\sigma^2)^{-3/2} \exp\left(-\frac{1}{2\sigma^2}(\mathbf{x} - \mathbf{x}_{n'})^2\right)$$

Lars Kai Hansen's algorithm with Newton optimization for optimizing the kernel width. Available in Brede Toolbox (Matlab).

Modeling anatomical labels in BrainMap



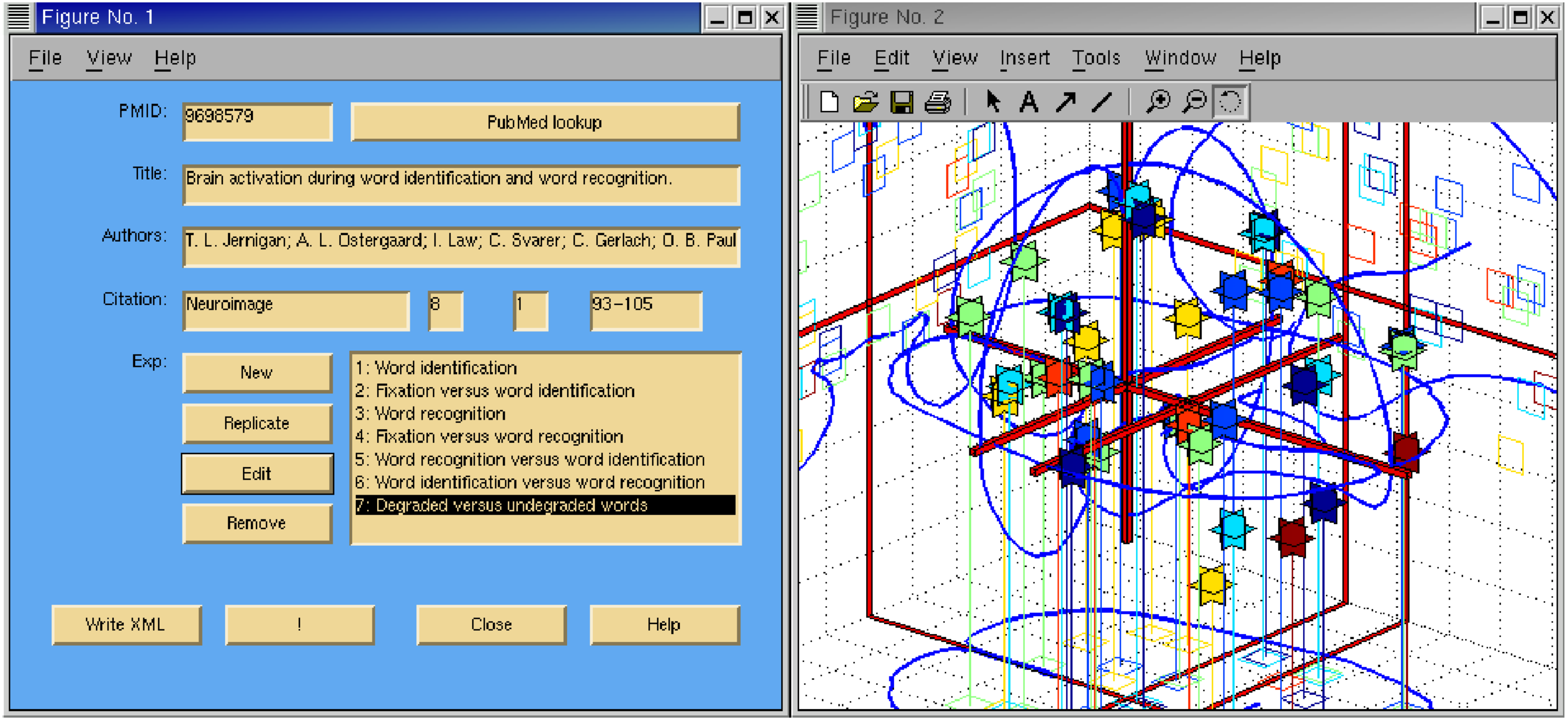
Finding outliers in BrainMap by looking at coordinates located in areas with low probability density.

Here $p(\mathbf{x}|l = \text{cerebellum})$ with a coordinate in the anterior part of the brain

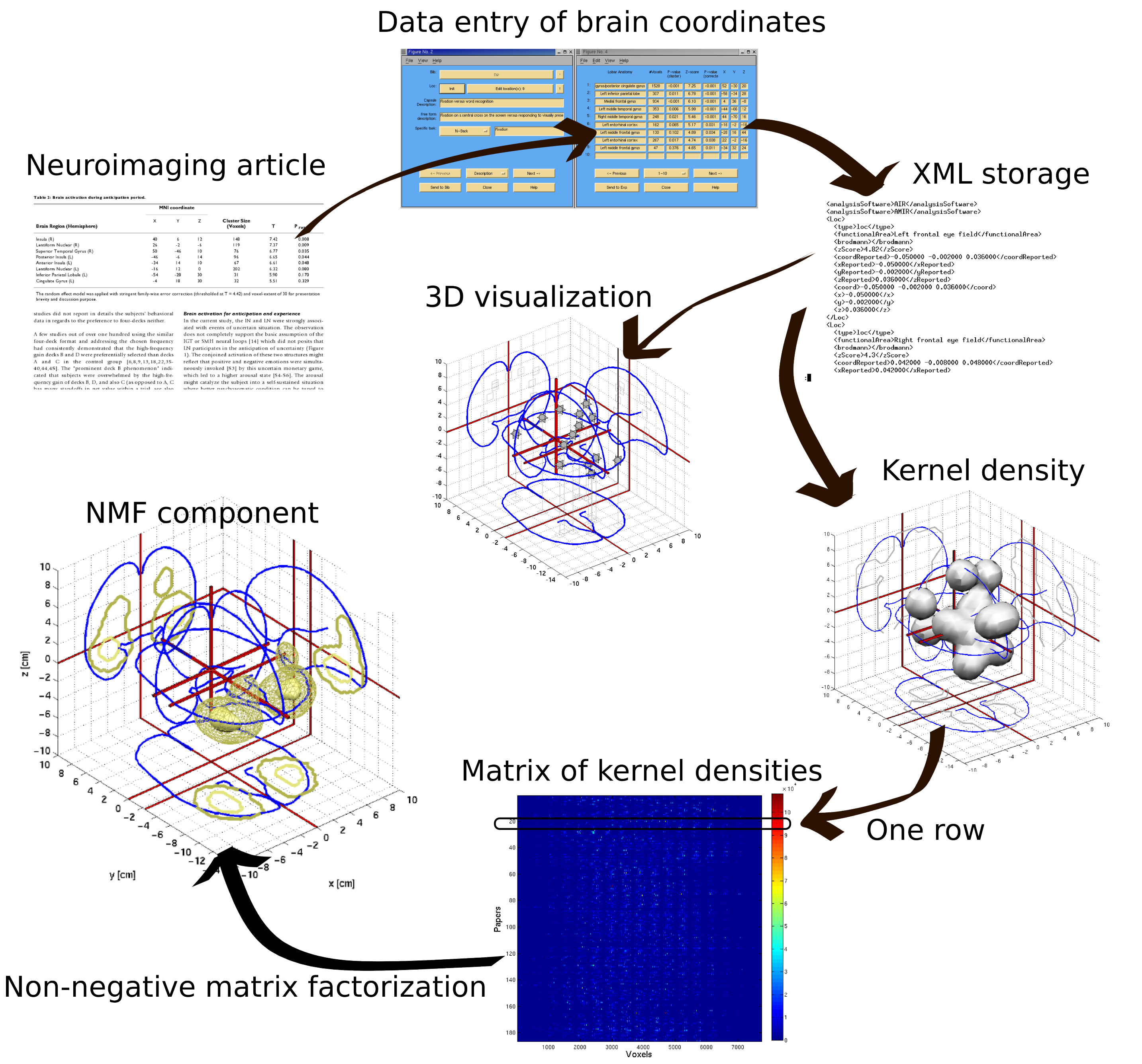
Typos: centimeter/millimeter, left/right, . . .

Algorithm also run for the Brede Database.

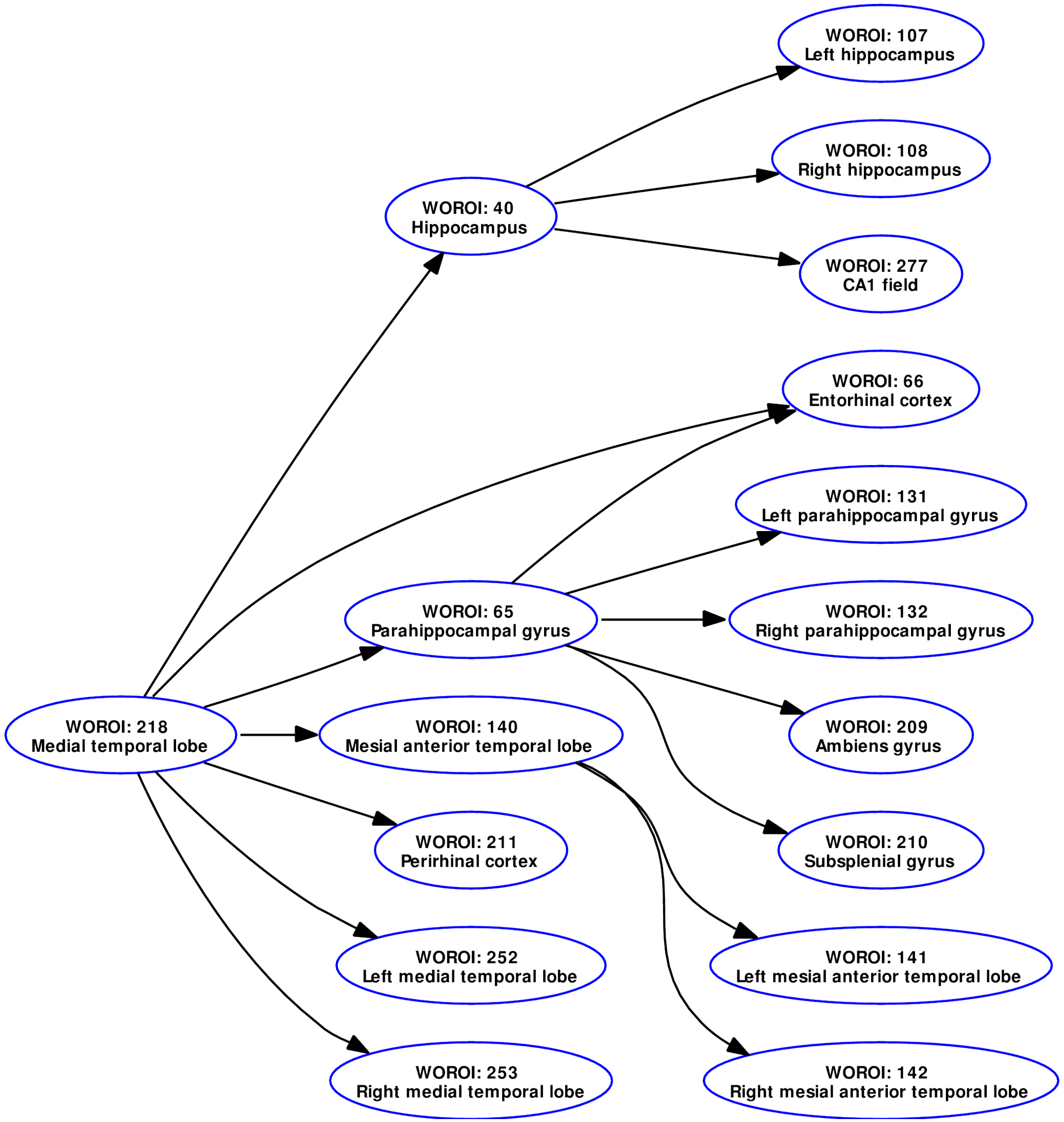
Brede Database



Matlab graphical user interfaction program for data entry and visualization of studies with Talairach coordinates.


Data entry of brain coordinates
Neuroimaging article
XML storage
3D visualization
Kernel density
NMF component
Matrix of kernel densities
One row
Non-negative matrix factorization
Papers
Voxels
z [cm]
y [cm]
x [cm]

Brede Database neuroanatomy taxonomy



Hierarchy of brain regions.

Based on another neuroanatomical database 'BrainInfo/NeuroNames' (Bowden and Martin, 1995) and atlases, e.g. 'Mai atlas' (Mai et al., 1997).

Fields recorded: Canonical name, variation in names, abbreviations, links to NeuroNames and other databases.

Graph constructed with GraphViz (Gansner and North, 2000).

Functional segregation in brain regions

For a brain region = 1 to 313 brain regions:

Step 1: Get all coordinates for the specific area, build a density model, exclude coordinates that are outliers

Step 2: Determine themes of the brain area with text mining on abstracts that contain coordinates within the brain area

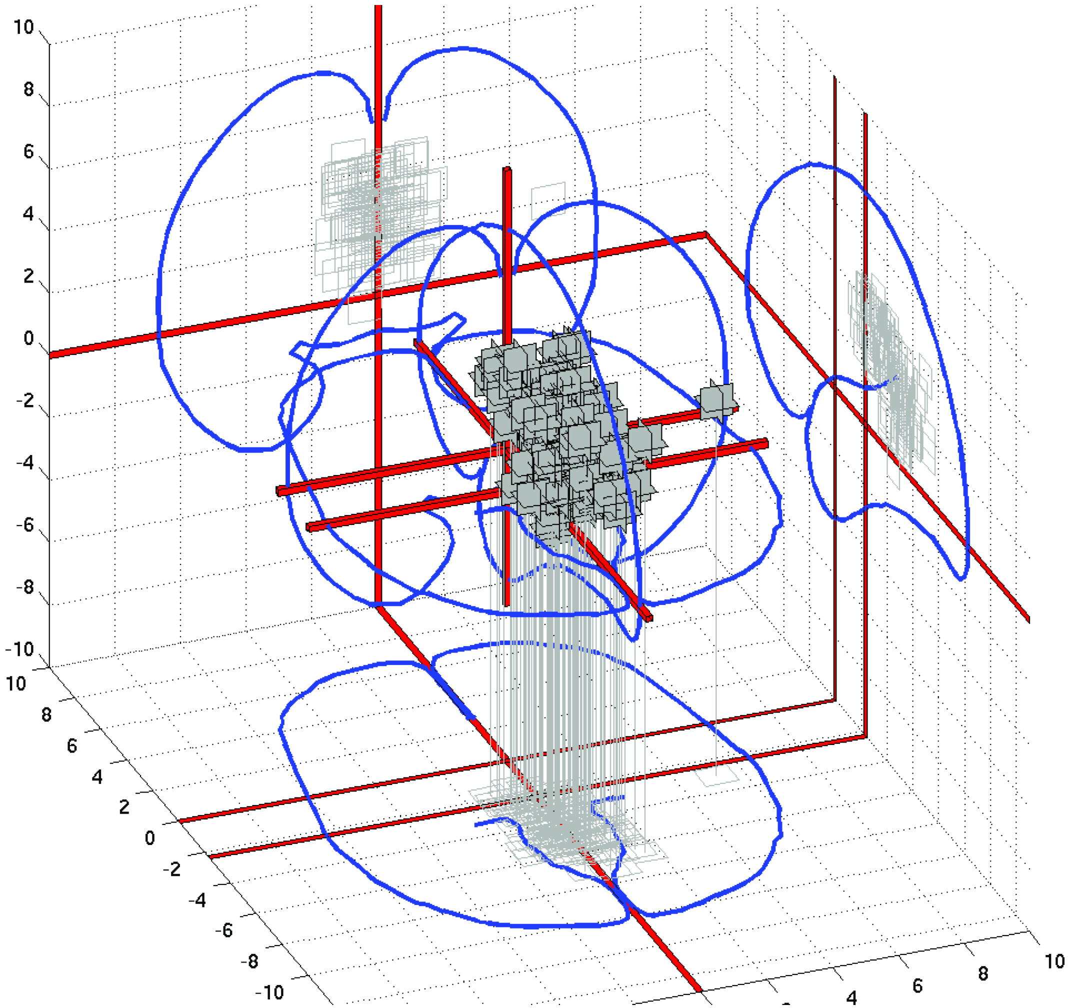
Step 3: Determine whether specific themes are spatially clustered in the brain area by testing whether two sets of coordinates are separated.

end

Step 4: Intertwine results from all brain regions

(Nielsen et al., 2006; Nielsen et al., 2005).

Step 1: Identify coordinates



Simple SQL-like command in Matlab to find locations

Corner cube visualization of 116 “posterior cingulate” coordinates found

An outlier: “Right postcentral gyrus/posterior cingulate gyrus” from (Jernigan et al., 1998).

Build kernel density estimate of the coordinates.

Step 2: Bag-of words matrix

	'memory'	'visual'	'motor'	'time'	'retrieval'	...
Fujii	6	0	1	0	4	...
Maddock	5	0	0	0	0	...
Tsukiura	0	0	4	0	0	...
Belin	0	0	0	0	0	...
Ellerman	0	0	0	5	0	...
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$

For the further analysis: Include all papers that contain one or more of coordinates found.

Representation of the abstracts of the papers in a bag-of-words matrix: (abstract $\times$ words)-matrix $\equiv \mathbf{X}(N \times P)$.

Exclude a large list of word: Anatomical, "stop words", ...

Step 2: Non-negative matrix factorization

Non-negative matrix factorization (NMF) decomposes a non-negative data matrix $\mathbf{X}(N \times P)$ (Lee and Seung, 1999)

$$\mathbf{X} = \mathbf{W}\mathbf{H} + \mathbf{U}, \tag{1}$$

where $\mathbf{W}(N \times K)$ and $\mathbf{H}(K \times P)$ are also non-negative matrices.

"Euclidean" cost function for

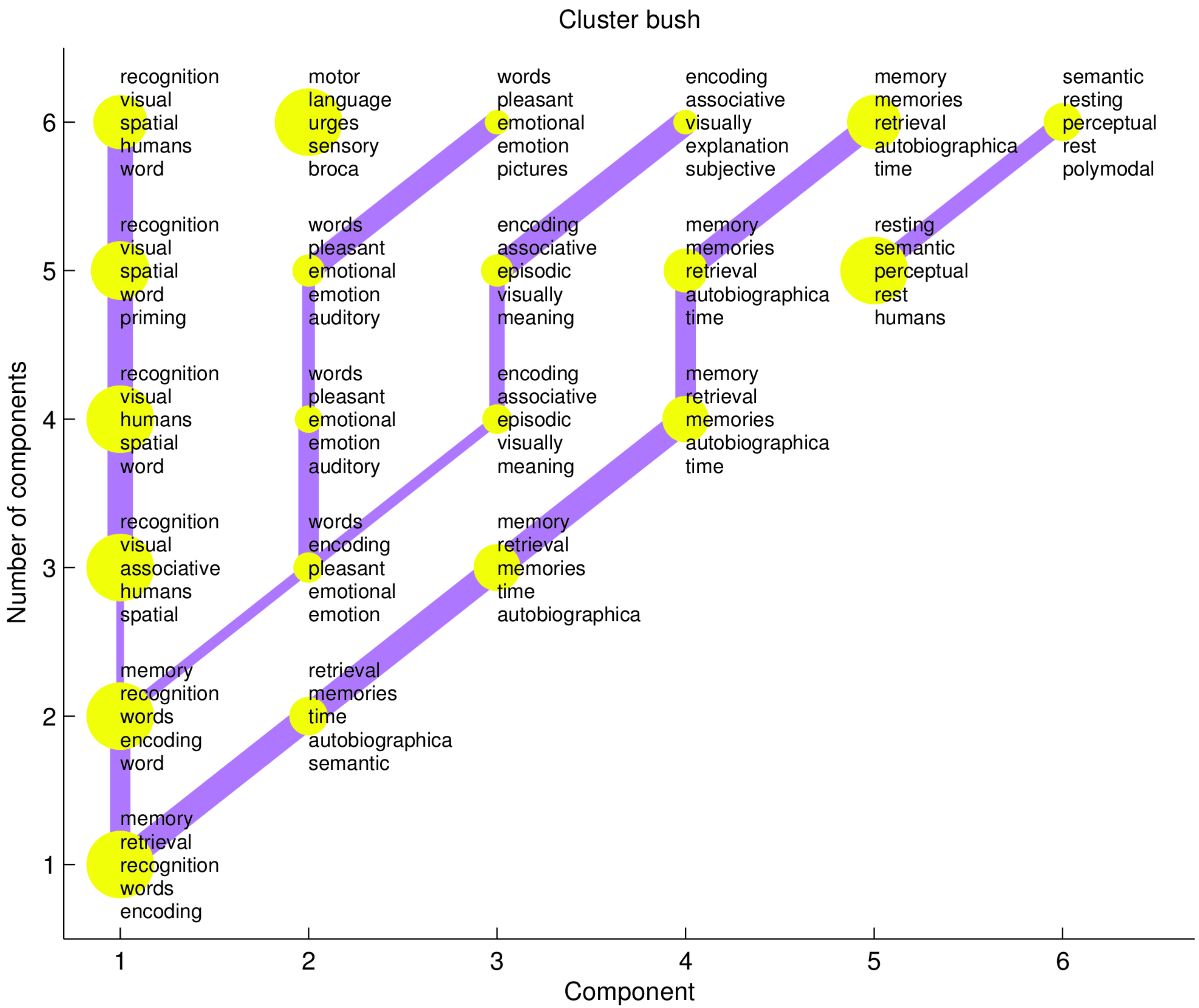
$$E_{\text{“eucl”}} = ||\mathbf{X} - \mathbf{W}\mathbf{H}||_F^2 \tag{2}$$

Iterative algorithm (Lee and Seung, 2001)

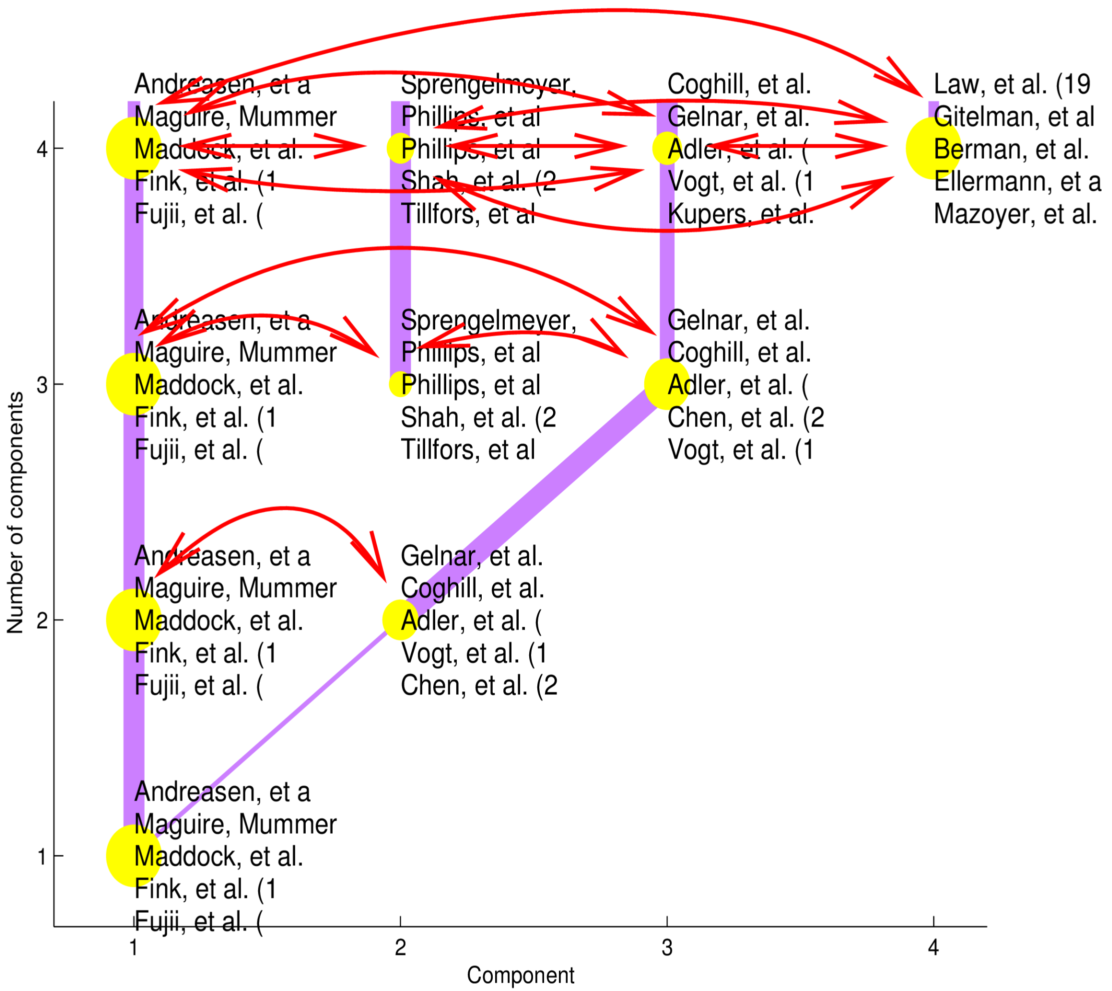
$$\mathbf{H}_{kp} \leftarrow \mathbf{H}_{kp} \frac{\left(\mathbf{W}^\mathsf{T}\mathbf{X}\right)_{kp}}{\left(\mathbf{W}^\mathsf{T}\mathbf{W}\mathbf{H}\right)_{kp}} \tag{3}$$

$$\mathbf{W}_{nk} \leftarrow \mathbf{W}_{nk} \frac{\left(\mathbf{X}\mathbf{H}^\mathsf{T}\right)_{nk}}{\left(\mathbf{W}\mathbf{H}\mathbf{H}^\mathsf{T}\right)_{nk}}. \tag{4}$$

Step 2: ‘Medial temporal lobe’ NMF result



Step 3: Test spatial distribution

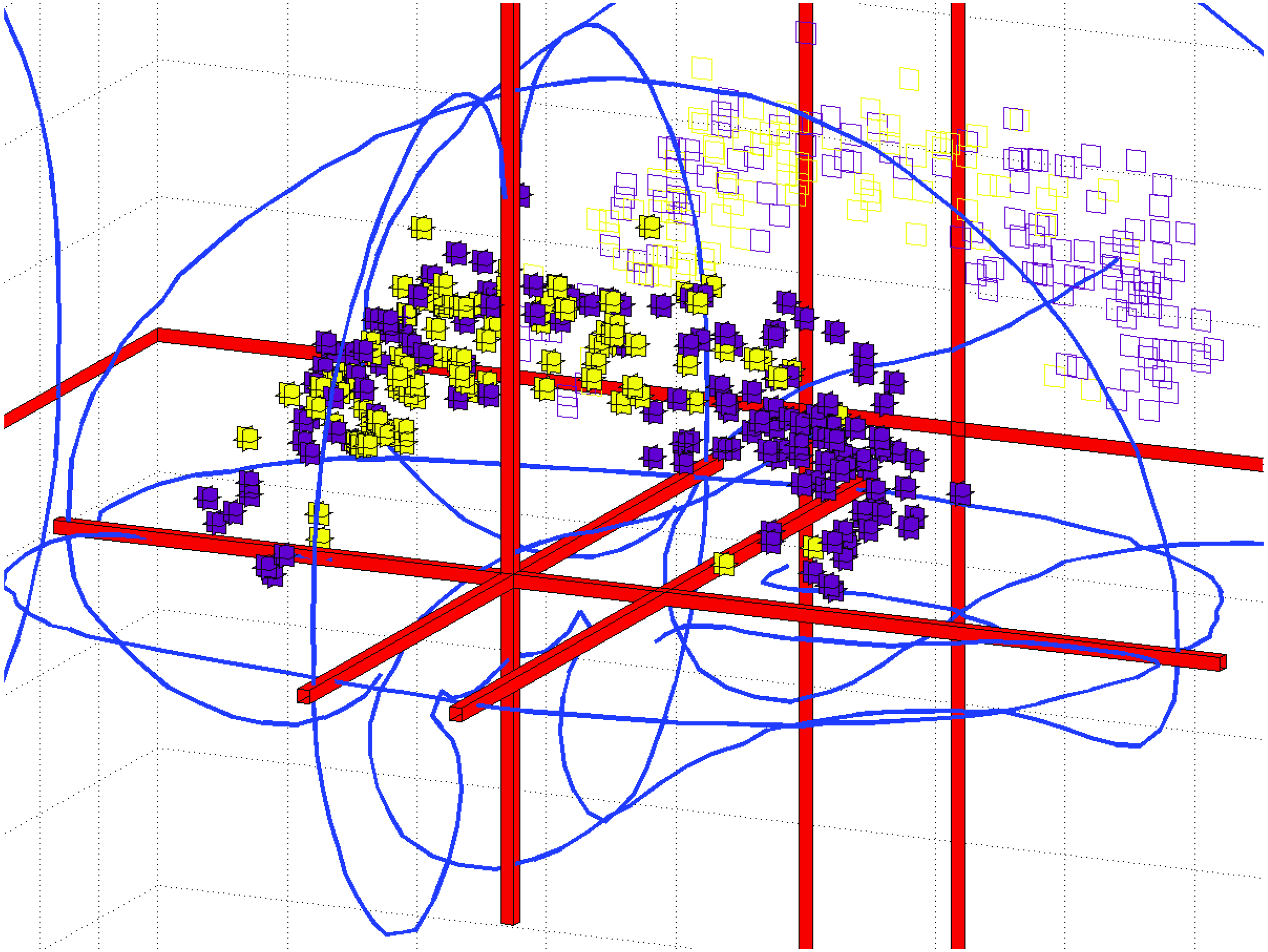


Extract locations from grouped papers.

Test if the spatial distribution of locations for a group is different from the distribution from an other group with Hotelling's T^2 or convex hull pelling permutation test.

All possible tests within a level of non-negative matrix factorization are performed.

Step 4: 'Cingulate gyrus'



Coordinates associated with topics on: pain, painful vs. memory, retrieval

Combining text and coordinate directly

Construct a functional parcellation of the brain based on combined text and coordinate analysis (Nielsen et al., 2004; Nielsen, 2009).

Brede Database with neuroimaging papers.

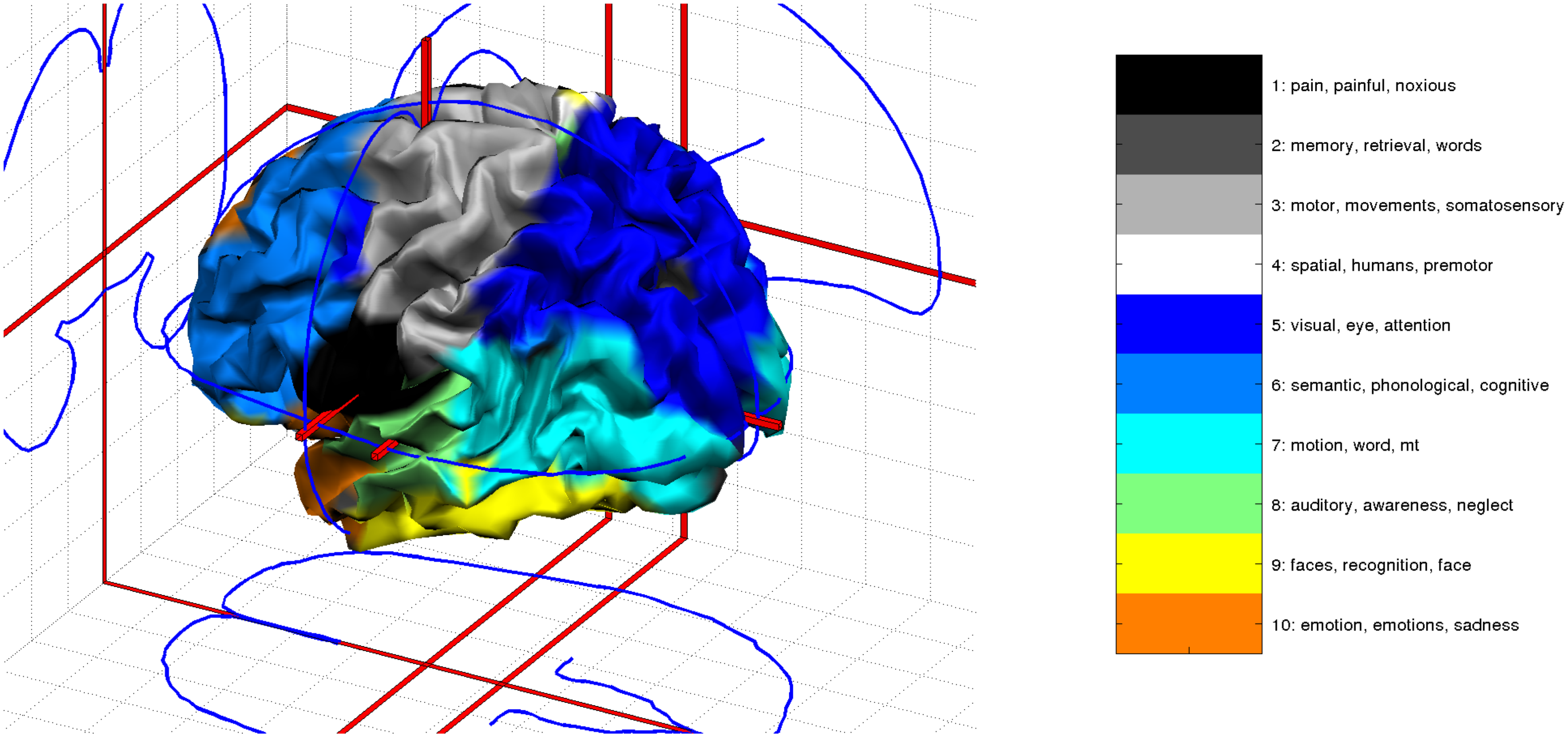
Bag-of-words matrix from abstracts, scaling, and stop words elemination getting a (paper $\times$ words)-matrix, $\mathbf{X}_1$

Kernel density estimates from coordinates contained in the papers getting a (papers $\times$ vertices)-matrix or (papers $\times$ voxels), $\mathbf{Y}$.

Product matrix: $\mathbf{Z}_1 = \mathbf{Y}'\mathbf{X}_1$ getting a (vertices $\times$ labels)-matrix.

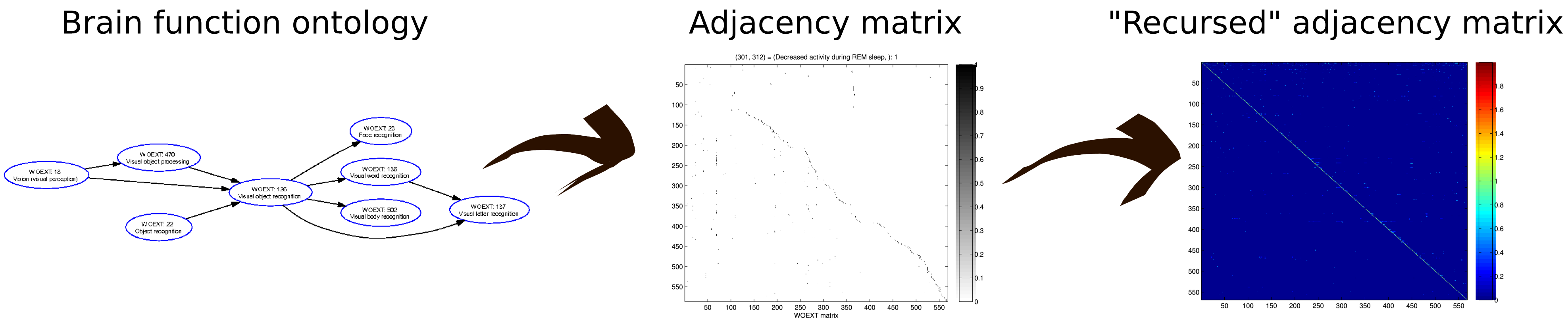
Approximative non-negative matrix factorization: $\mathbf{W}\mathbf{H} \approx \mathbf{Z}_1$ getting a (vertices $\times$ topics)-matrix, $\mathbf{W}$ and a (topic $\times$ words)-matrix, $\mathbf{H}$.

Functional parcellation of the cortex



Winner-take-all function on $\mathbf{W}$ (the surface) and $\mathbf{H}$ (the legend).

Brain function ontology



Experiment label ('external components', brain function ontology, cognitive ontology) organized in a directed graph (Nielsen, 2005).

This graph can be converted to an adjacency matrix.

An experiment (i.e. contrast) in Brede Database may be labeled with an item from the ontology.

Functional parcellation with cognitive ontology

Brede Database with neuroimaging paper.

Adjacency matrix of experiment label ('external components', brain function ontology) graph ($\mathbf{C}$) propagated $\mathbf{D} = \sum_i (\lambda \mathbf{C})^i$.

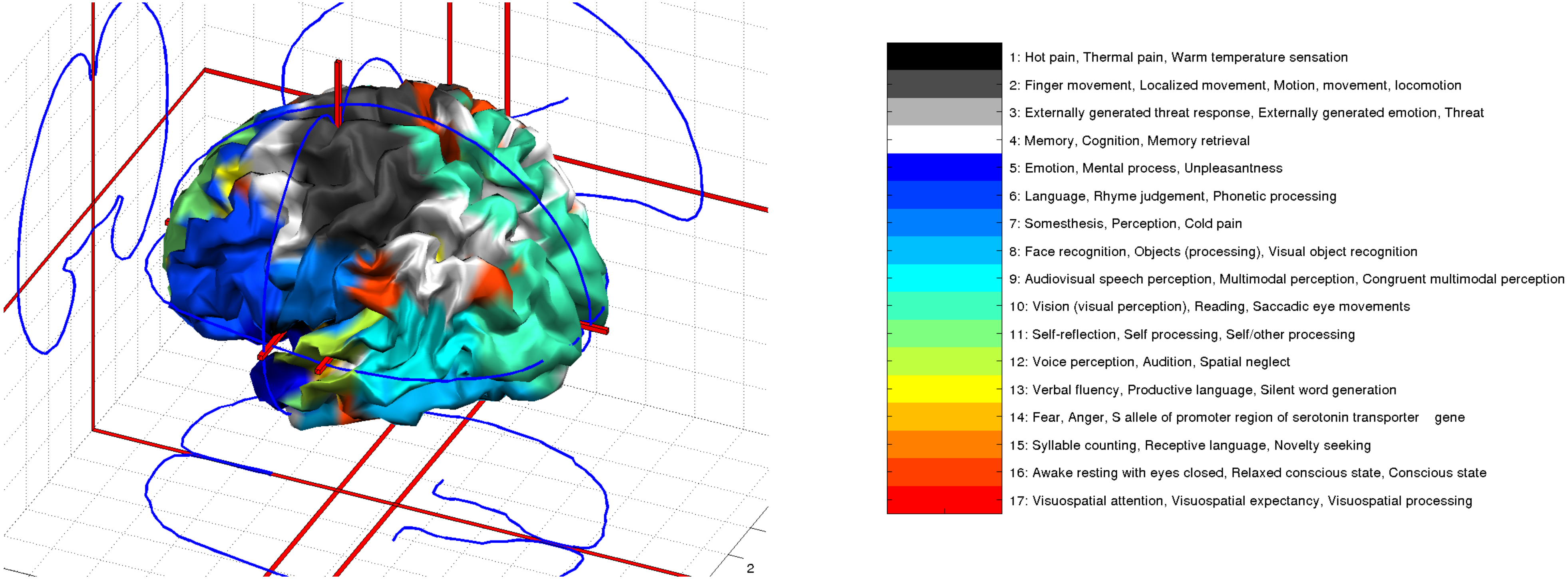
Propagated experiment label (experiments $\times$ labels)-matrix $\mathbf{X}_2 = \mathbf{TD}$, where the (experiments $\times$ experiment labels)-matrix $\mathbf{T}$ represents the (manual) label of each experiment.

Kernel density estimates from coordinates contained in the experiment getting a (experiments $\times$ vertices)-matrix or (experiments $\times$ voxel)-matrix ($\mathbf{Y}$).

Product matrix: $\mathbf{Z}_2 = \mathbf{Y}'\mathbf{X}_2$ getting a (vertices $\times$ experiment labels)-matrix.

Approximative non-negative matrix factorization: $\mathbf{WH} \approx \mathbf{Z}_2$ getting a (vertices $\times$ topics)-matrix ($\mathbf{W}$) and a (topic $\times$ words)-matrix ($\mathbf{H}$)

Brain atlas constructed from experiment labels



Winner-take-all function on $\mathbf{W}$ (the surface) and $\mathbf{H}$ (the legend with items from the experiment labels/ontology).

Brede tools

Presently developing a Python Brede Package with features such as Features: Handling of data from Brede Wiki, Neurosynth, word lists, data sets, surfaces, . . . : https://github.com/fnielsen/brede

Brede Database: http://neuro.compute.dtu.dk/services/brededatabase/

Brede Toolbox (matlab): http://neuro.compute.dtu.dk/software/brede/

Brede Wiki: http://neuro.compute.dtu.dk/wiki/.

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