A functional meta-analytic atlas with non-negative partial least squares

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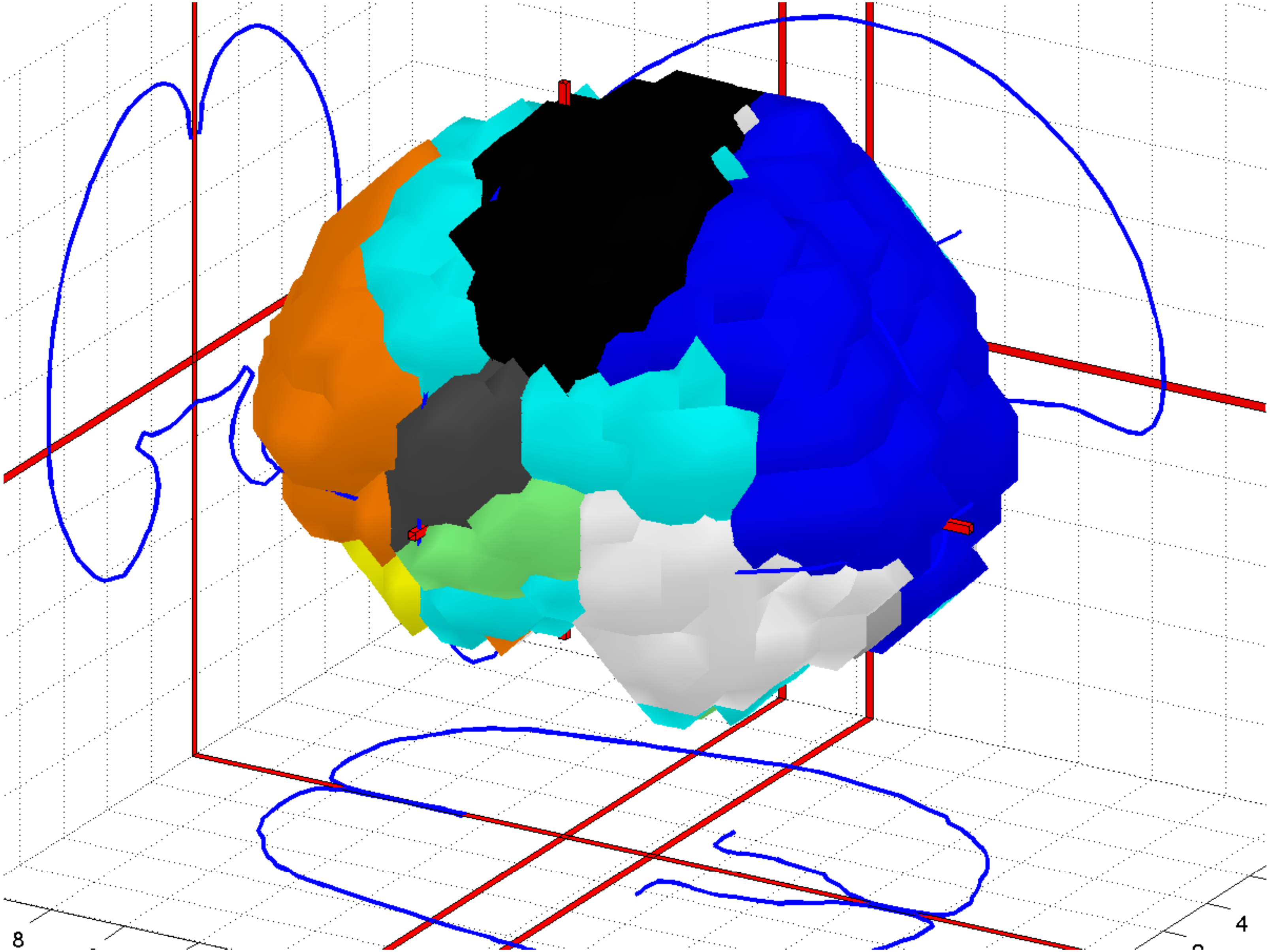
190 T-PM (Tuesday afternoon)

Summary

Generation of a meta-analytic functional atlas for the entire brain by automatic unsupervised data mining . . .

. . . where each voxel is labeled with words describing brain function,

. . . like previously done for brain lesions (Kleist, 1934).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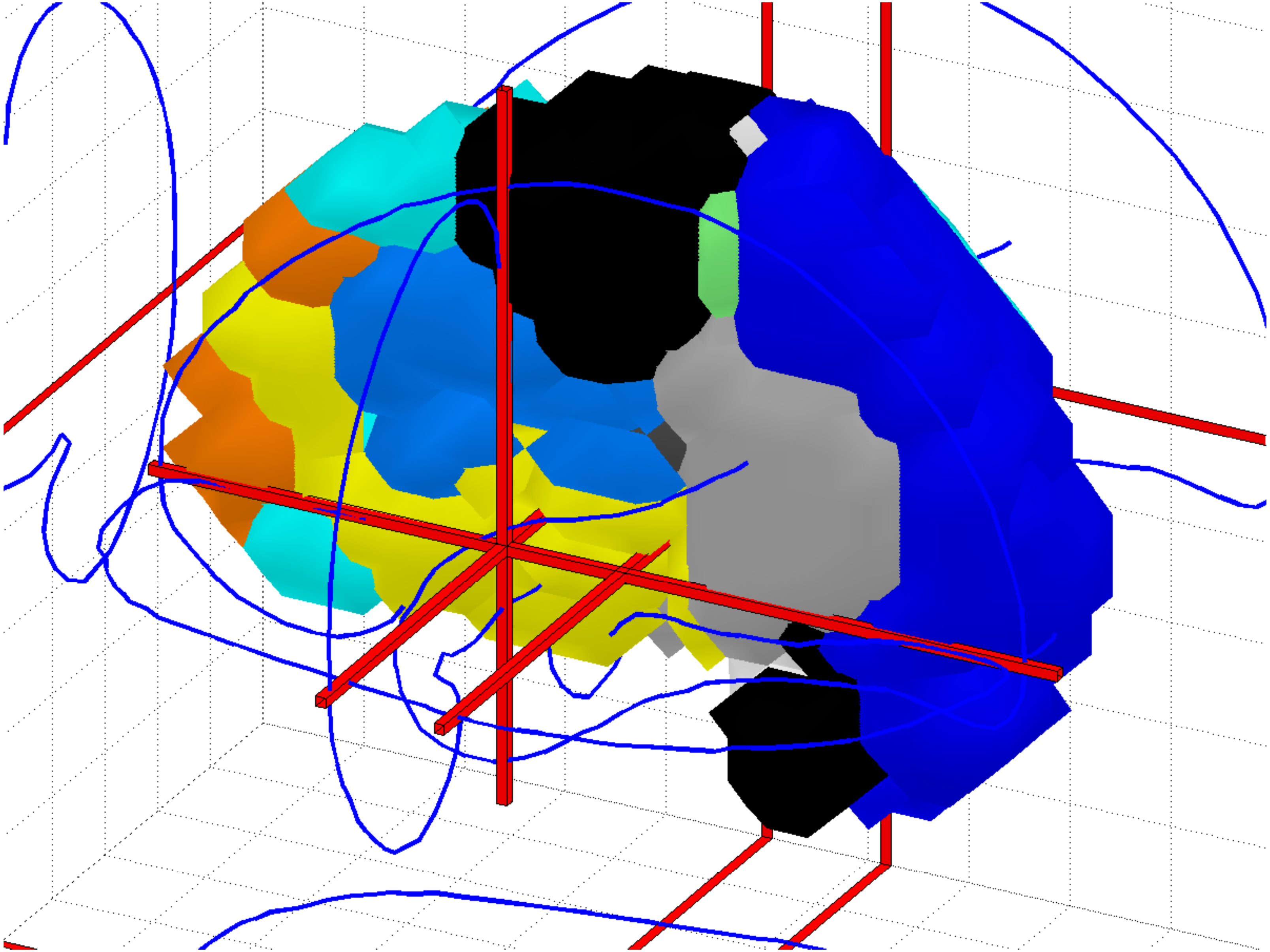
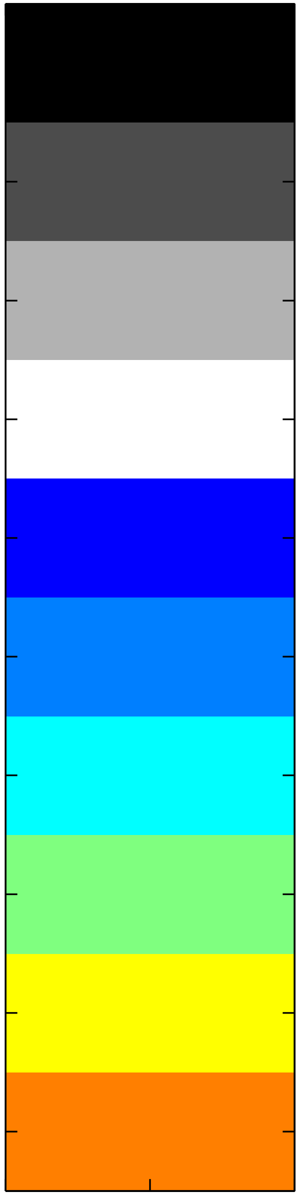




1: motor, movements, somatosensory, hand, finger

2: painful, perception, thermal, heat, warm

3: retrieval, neutral, words, encoding, episodic

4: faces, perceptual, face, recognition, category

5: visual, eye, time, attention, mental

6: pain, noxious, verbal, unpleasantness, hot

7: memory, alzheimer, autobiographical, rest, memories

8: auditory, spatial, neglect, awareness, language

9: emotion, emotions, disgust, sadness, happiness

10: semantic, phonological, cognitive, decision, judgment

Question

How is this done?

Method

The data material is a **database of functional neuroimaging studies** with stereotaxic coordinates.

Perform **non-negative matrix factorization** on the product matrix

$$\mathbf{Z} = \mathbf{X}^{\mathsf{T}}\mathbf{Y}$$

...where $\mathbf{X}$ is a **bag-of-words** matrix constructed from abstract words

...and where $\mathbf{Y}$ is a matrix with volumes constructed from **voxelizations** of the stereotaxic coordinates in each article.

Here we term non-negative matrix factorization on a product matrix for "**non-negative partial least squares**", cf. (McIntosh et al., 1996).

Brede Database

Brede Database contains data from published functional neuroimaging studies (Nielsen, 2003).

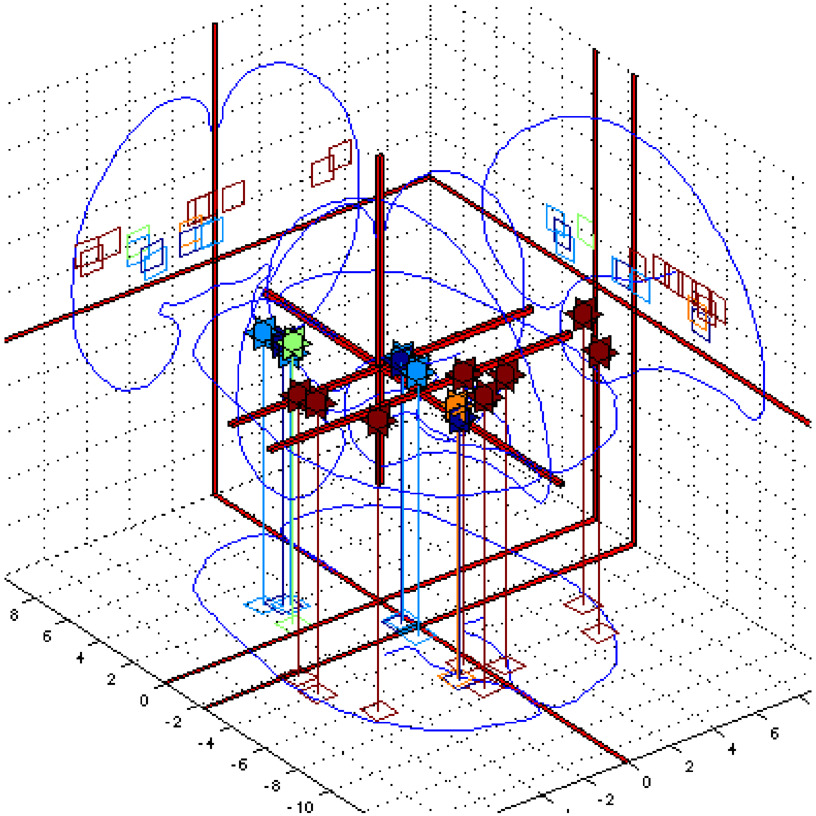
. . . with a structure much like the BrainMap database (Fox and Lancaster, 1994; Fox et al., 1994)

We use only the **abstracts** and the **stereotaxic coordinates** from the Brede Database.

Brede Database (now!) contains information from 185 articles with 3906 stereotaxic coordinates — which are transformed to Talairach space (Talairach and Tournoux, 1988).

WOBIB: 185 - Paulesu, et al. (1997) Functional heterogen ...

Eraldo Paulesu; Ben Goldacre; Paola Scifo; Stefano F. Cappa; Maria Carla Gilardi; Isabella Castiglioni; Daniela Perani; Frruccio Fazio. *Functional heterogeneity of left inferior frontal cortex as revealed by fMRI*. *NeuroReport* **8**(8):2011-2017, 1997. PMID: 9223094. FMRIDCID: . WOBIB: 185.



USING functional magnetic resonance imaging (fMRI), we mapped brain activity in six normal volunteers during two silent verbal fluency tasks, one with a phonemic (letter) cue and one with a semantic (category) cue. In comparison with resting state, both tasks activated the anterior triangular portion of the left inferior frontal gyrus (IFG or F3, for third frontal gyrus) and the left thalamus. There were also areas activated in one task but not in the other: the posterior opercular portion of the left IFG for phonemic fluency, and the left retrosplenial region for semantic fluency. Our findings concur with normal psychophysical data and neuropsychological observations to suggest the recruitment of two overlapping but dissociable systems for the two tasks, and demonstrate functional heterogeneity within the left IFG (Broca's area), where the opercular portion is responsible for obtaining access to words through a phonemic/articulatory route.

X-matrix: a “bag-of-words”

	‘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	...
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$

Representation of the abstract of the articles in a “bag-of-word”. Table/matrix counts how often a word occurs in an abstract

Matrix $\mathbf{X}(N \times Q) = \mathbf{X}(\text{articles} \times \text{words})$.

. . . where each element is actually set to the square root of the count.

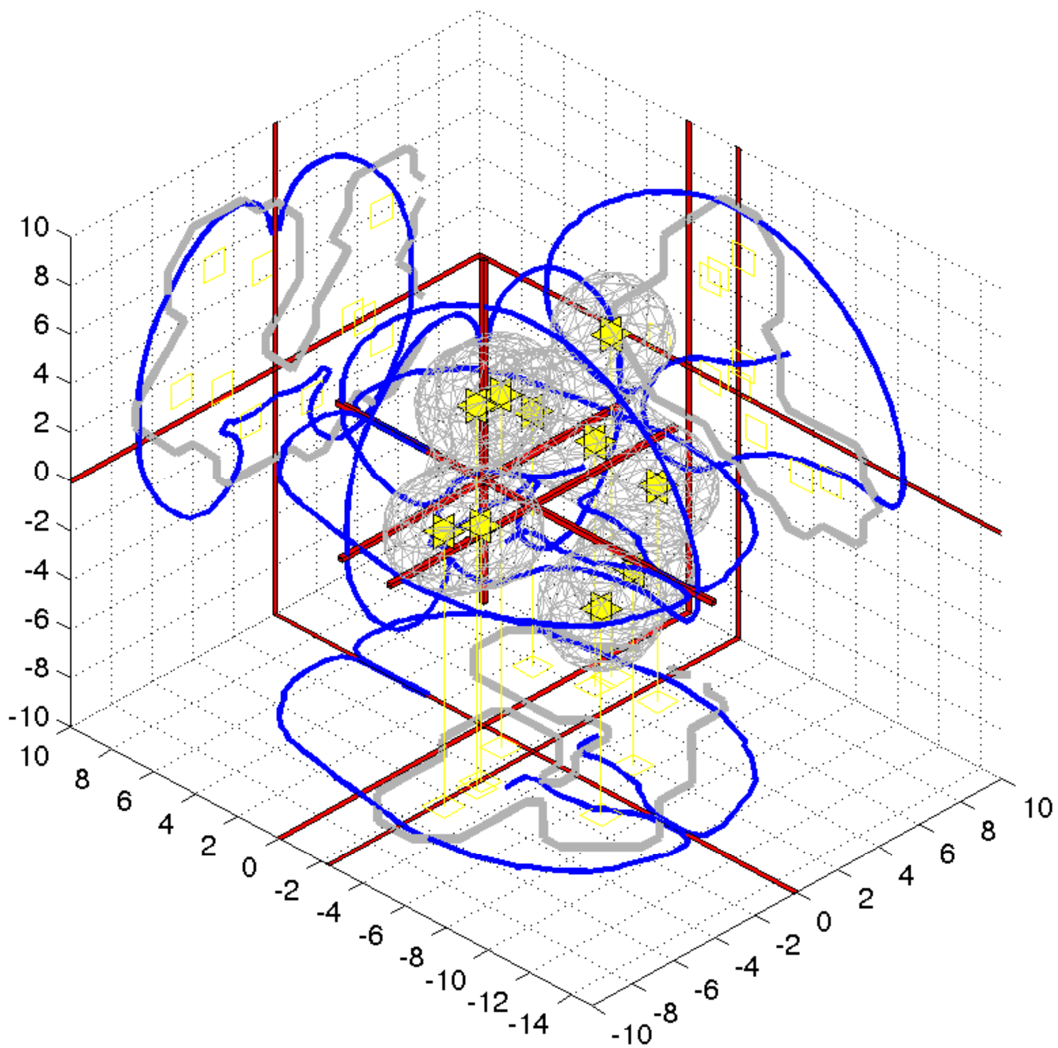
Words excluded from matrix: "Stop words"

a a's aberrant aberrations abilities ability ablated ablations able abnormal abnormalities abnormality abolished about above absence absent absolute abstract abundant abuse . . . covariance covariate covarying covered coverslip cranial criteria criterion critical cross crucial . . . year years yellow yes yet yield yielded yl you you'd you'll you're you've young younger your yours yourself yourselves z zero zone zones

amygdala amygdaloid angular anterior area basal bilateral brain brainstem calcarine callosomarginalis caudal caudate central centre cerebellar cerebellum cingulate cingulum claustrum . . . pallidum pallidus paracentral parahippocampal parallel parietal parieto partietal peduncle periamygdaloid periaqueductal perirhinal planum pole pons . . . supramarginal tail tegmentum temporal temporale temporo temporoparietal temproal thalamic thalamus uncus ventral ventrolateral ventromedial ventroposterior vermis vi viib

— Stop word list setup in (Nielsen et al., 2005).

Y-matrix: Coordinates to volume



Stereotaxic coordinates in an article converted to volume-data by filtering each point (Nielsen and Hansen, 2002).

One volume for each article,

. . . and each volume one row in the matrix:

$$\mathbf{Y}(N \times Q) = \mathbf{Y}(\text{articles} \times \text{voxels})$$

Example: Grey wire frame indicating the isosurface in the volume generated from the yellow coordinates.

Voxelization

With M_n stereotaxic coordinates in the n'th article

... M_n Gaussian kernels in Talairach space $\mathbf{u}$ are placed on each of their stereotaxic coordinates $\boldsymbol{\mu}_m$ generating an unnormalized probability density

$$p_n(\mathbf{u}) = (2\pi\sigma^2)^{-3/2} \sum_{m}^{M_n} e^{-\frac{1}{2\sigma^2}(\mathbf{u}-\boldsymbol{\mu}_m)^2}$$

... where σ^2 is fixed to $\sigma = 10$mm,

... and where each $p_n(\mathbf{u})$ is weighted (α_n) with the inverse of the square root of the number of experiments in the article times the inverse of the square root of the number of coordinates in each experiment,

... and sampled on a regular 8 mm grid: $\mathbf{y}_{(n)} \equiv \alpha_n p_n(\mathbf{u})$

Only voxels within a mask defined by the labeled voxels in the AAL atlas (Tzourio-Mazoyer et al., 2002) are kept in the final $\mathbf{Y}$-matrix.

Non-negative matrix factorization

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

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

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

"Euclidean" cost function for

$$E_{\text{``eucl''}} = ||\mathbf{Z} - \mathbf{W}\mathbf{H}||_F^2 \tag{2}$$

Iterative algorithm (Lee and Seung, 2001)

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

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

Final steps

With the number of factors set from a rule of thumb to $K = \sqrt{N/2}$ (Mardia et al., 1979) we get

... $\mathbf{W}$ containing weights over words — the labels for brain function,

... and $\mathbf{H}$ containing weights over voxels for each factor, i.e., K volumes.

A winner-take-all function is applied on these two factorization matrices, so each word and each voxel are exclusively assigned to one and only one of the K factors

... and the results are plotted in a three-dimensional corner cube environment (Rehm et al., 1998) where each factor is given its own color.

Remarks

Results vary slightly from run to run depending on initialization of the factorization matrices, but the main conclusion is that:

. . . the results are well aligned with neuroscientific knowledge,

. . . though the results are somewhat affected by the idiosyncrasies of the Brede database, e.g., the results show that one factor loads heavily on words such as ‘pain’, ‘noxious’ and ‘heat’, and it associates with voxels mostly in and around the anterior cingulate, thalamus and insula. That pain associates with these areas has previously been noted (Ingvar, 1999), and that it dominates these areas over other brain functions is due to the many pain studies in the Brede database.

Another example is a factor that is labeled with ‘motor’, ‘movements’ and ‘somatosensory’ and appears in a band along the central sulcus and neighboring regions as well as in the cerebellum, — areas commonly known to be involved in sensorimotor functions.

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