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Automatic anatomical labeling of Talairach coordinates and generation of volumes of interest via the BrainMap database

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Abstract

We propose a method for automatic anatomical labeling of stereotaxic coordinates by bootstrapping using the already labeled coordinates in the literature (as recorded in BrainMap™) and give a measure for how probable the label is. Furthermore we are able to generate probabilistic based volumes of interest.

Introduction

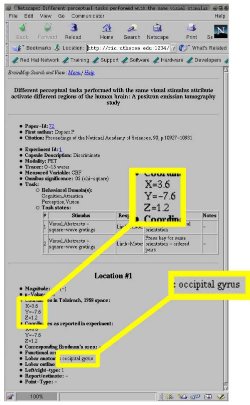
Areas of activation in functional neuroimaging is often communicated in the form of 3-dimensional Talairach coordinate or anatomical names. It is of interest to build models that can translate between the two representations, e.g., for meta-analyses or information retrieval purposes.

Automatic translation of Talairach coordinates to anatomical labels is, e.g., implemented in the Talairach Daemon [6] that is based on a digitization of the Talairach Atlas [10] and probabilistic atlases [3]. Other tools that correlate spatial and textual information are the *Computerized Brain Atlas* [11] and the *Electronic Brain Atlas* [9].

The assignment of a label to a stereotaxic coordinate is not straightforward due to variations in anatomy, functional activation and noise in the data [2], e.g., for small structures there might be little overlap between different anatomical scans [7]. Our method uses fuzzy/probabilistic assignment based on "consensus" in the scientific literature.

Data from BrainMap™

We obtain labeled coordinates from the BrainMap™ database [4, http://ric.uthscsa.edu]. As in [8] we downloaded it from the web and extracted the 3D Talairach coordinate ("Coordinates in Talairach, 1988 space") and the associated anatomical label ("Lobar Anatomy") for each location.



Each label is split into *terms* constructed from all subsets of words and phrase, e.g.

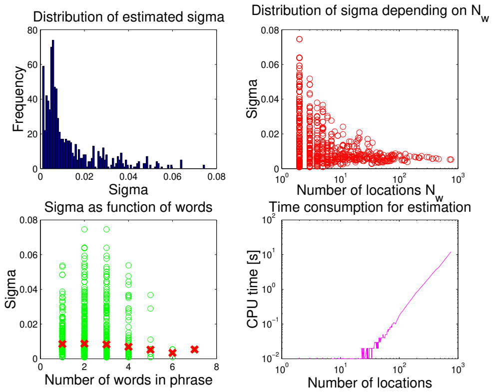
```
occipital gyrus →
   occipital
   gyrus
   occipital gyrus
```

This will generate a number of labels with little meaning, e.g., "posterior inferior" that is presently left for the user to ignore.

Generation of probability volumes

Density volumes are constructed as kernel density estimates also called Parzen windows or Specht kernel estimates operating in 3D Talairach space: Each location (represented by a 3-dimensional vector $\mathbf{x}$) is convoluted with an isotropic 3-dimensional Gaussian probability density function (PDF) with a width of σ^2. The combined PDF is the mean of all the Gaussian PDFs. The PDF is a *conditional on each term* w.

σ^2 is the only parameter in the model and it can either set to a fixed value or optimized in a leave-one-out cross-validation scheme [8].



The figure above shows some statistics on σ when estimated separately for each label with the cross-validation scheme. When there is a large number of locations for estimation σ = 5mm – 1cm.

Labeling

Labeling of a new location is done by comparing either the density $(0 < p(\mathbf{x}) < \infty, \int p(\mathbf{x})\, d\mathbf{x} = 1)$ or the probability $(0 < P(\mathbf{x}) < 1)$ for each label. The probability (the P-value) is found by constructing a density volume and summing the densities from all voxels below the density value for the present Talairach coordinate $\mathbf{x}$ for a given word/phrase w

$$P(\mathbf{x}|w) = \sum_{p(\mathbf{x}'|w)<p(\mathbf{x}|w)} p(\mathbf{x}'|w)\,/\,Z, \qquad (1)$$

where Z is the normalization constant, — the volume of a voxel. Equal weight is given for each label $P(w) = 1$ and the P-values are sorted and presented to the user in a list. This labeling scheme generates non-exclusive labels for each location.

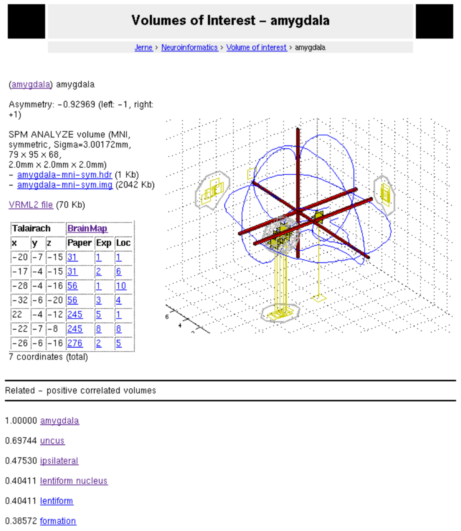
If only the density is required there are two ways in which the location can be labeled:

- Compute the densities *on the fly* and sort them. Estimation of σ is time consuming, so it should be computed in advance or set to a fixed value.
- Compute the densities for a full volume in a sampled grid and report the label for the grid point closest to the location. This requires a large amount of memory.

The density across the full volume is required if the probability is used to rank the labels.

Example volume

We construct static Web HTML files with one volume for each label which each contain a Corner Cube visualization (both as images and 3D VRML files), a list the locations with links to BrainMap™, and a list the related volumes.


Volumes of Interest – amygdala

Jerne > Neuroinformatics > Volume of interest > amygdala

(amygdala) amygdala

Asymmetry: −0.92969 (left: −1, right: +1)

SPM ANALYZE volume (MNI, symmetric, Sigma=3.00172mm, 79 × 95 × 68, 2.0mm × 2.0mm × 2.0mm)
- amygdala-mni-sym.hdr (1 Kb)
- amygdala-mni-sym.img (2042 Kb)

VRML2 file (70 Kb)

Talairach			BrainMap		
x	y	z	Paper	Exp	Loc
−20	−7	−15	31	1	1
−17	−4	−15	31	2	6
−28	−4	−16	56	1	10
−32	−6	−20	56	3	4
22	−4	−12	245	5	1
−22	−7	−8	245	8	8
−26	−6	−16	276	2	5

7 coordinates (total)

Related – positive correlated volumes

1.00000 amygdala

0.69744 uncus

0.47530 ipsilateral

0.40411 lentiform nucleus

0.40411 lentiform

0.38572 formation

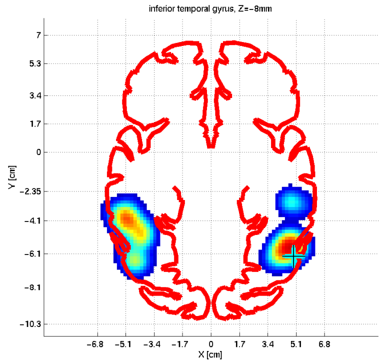
Some of the labels show a marked right or left dominance (apart from obvious labels such as "left" and "right"), e.g., "motor" locations are predominantly found in the left hemisphere, probably because the right hand is often applied in the functional neuroimaging experiment. We compute an asymmetry measure by counting the number of locations in the left and right hemisphere and use a test in the binomial distribution. This measure is also reported on the HTML pages and an index page is generated with a sorted list of asymmetry measures.

Volumes are produced that are in line with the MNI space and with voxel size and field of view taken from the default of SPM99. All locations are transformed with Brett's nonlinear transformation [1] and the locations are doubled by mirroring in the x-coordinate to account for the asymmetry. These volumes can potentially be used as masks in region of interest analyses.

Example labeling

A location from [5, table 1, entry 1] labeled "R. Inferior temporal gyrus", (50, -64, -12), BA37. With Brett's nonlinear transformation [1] from MNI to Talairach space: MNI $\rightarrow$ (Brett) $\rightarrow$ Talairach: (49.5 -62.5 -7). Below is the location labeled with the Talairach Daemon and by the author of [5].

Labeler	Label
Author	R. Inferior temporal gyrus
TD	Right Cerebrum,Occipital Lobe, Sub-Gyral,White Matter,*
TD	Occipital_Lobe 7.70, Temporal_Lobe 62.35



Above the probability volume for "inferior temporal gyrus" at $z = -8$mm.

Dens.	Prob.	#	Lobar anatomy
12472	0.934	5	occipito
10143	0.932	37	inferior temporal gyrus
15590	0.926	4	occipito temporal
2528	0.916	367	inferior
3917	0.907	48	ventral
9671	0.902	66	inferior temporal
15375	0.802	7	ventral surface
15375	0.802	7	surface
1200	0.788	762	gyrus
9475	0.771	22	inferior occipital

The example location labeled with the present method and sorted according to probability. # is the number of locations defining the volume.

Conclusion and further issues

- A "bootstrapped Talairach Daemon": Automatic anatomical labeling of locations as the Talairach Daemon based on annotation in the literature.
- A probability value can be assigned to each non-exclusive label. This gives an idea of the validity of associating a given stereotaxic coordinate with a single phrase.
- Generation of volumes of interest: A large number of volume of interest can be constructed and used in region-based analysis.
- The BrainMap™ data contains outliers [8] that should be excluded from the data.
- Furthermore, the regions and labeling are dependent on the use of the language and the experimental settings rather than the true structure, e.g., some labels show an left/right asymmetry mostly due to popular experimental designs (such as right hand motor studies). The volumes of interest should be used with caution.
- Some of the tools for this analysis are implemented in the *Brede* Matlab toolbox available at http://hendrix.imm.dtu.dk/software/brede/.
- Probability volumes in MNI space in the SPM ANALYZE format and 3D visualizations are available from http://hendrix.imm.dtu.dk/services/jerne/.

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