Analysis of Data from the BrainMap database

Finn Årup Nielsen

Informatics and Mathematical Modelling
Technical University of Denmark
DK-2800 Lyngby, Denmark

Email: fn@imm.dtu.dk
WWW: http://www.imm.dtu.dk/~fn

OVERVIEW

- Neuroinformatics.
- The BrainMap database.
- Novelty detection (outlier detection) with anatomical labels and 3D Talairach coordinates.
- Automatic labeling.

NEUROINFORMATICS

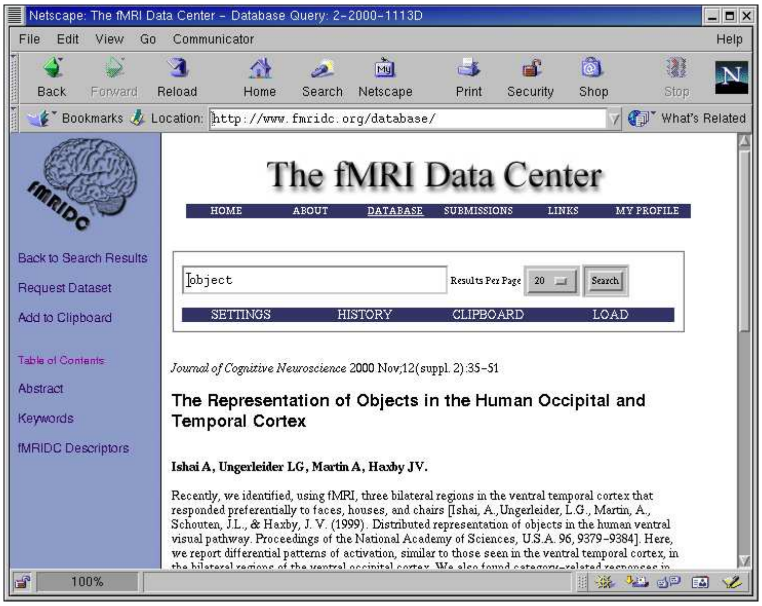


Figure 1: Screenshot from fMRI data center web-page.

"Neuroinformatics"

- Neuroscience + informatics
- Primary data sources from experiments, e.g., scans.
- Secondary data sources: *BrainMap*, *Talairach Daemon*, fMRIDC, Connectivity databases (CoCoMac, CoCoDat, ...), "microscopic neuroscience" (SenseLab, LGIC, ...), literature (PubMed, ResearchIndex, Publisher's website, ...).
- Computerized automatic analysis

BRAINMAP

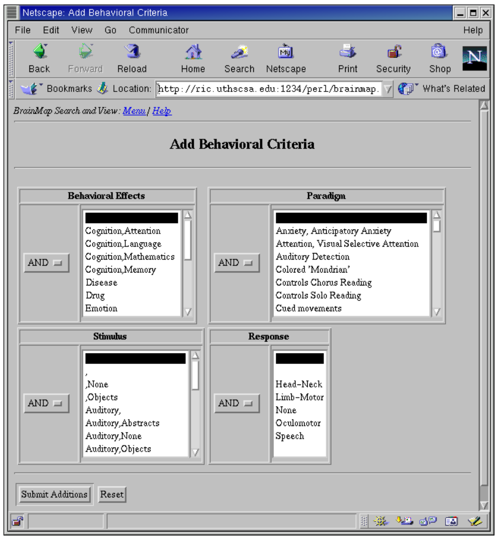


Figure 2: Behavioral criteria query web-page.

- Database with results from functional neuroimaging studies. *Research Imaging Center*, San Antonio, http://ric.uthscsa.edu. (Fox and Lancaster, 1994)
- Consists of: Entry + Database + Search and View.
  - "BrainMap Entry". Limited distribution.
  - Database. Oracle SQL Relational database.
  - "BrainMap Search & View". Version with visualization for SUN computer. Internet version.
- 3 different data types + behavior
  - Paper (225): Bibliographic information
  - Experiment (771): Description of the paradigm
  - Location (7683): Talairach coordinate, anatomical and Brodmann labels (3935 location with this)

MODELING OF ANATOMICAL LABELS AND 3D TALAIRACH LABELS

- Modeling the relation between *3D Talairach Coordinates* (three dimensional continuous value) and *anatomical labels* ("lobar anatomy" text field BrainMap field).
- Novelty detection: Discover unusual entries.

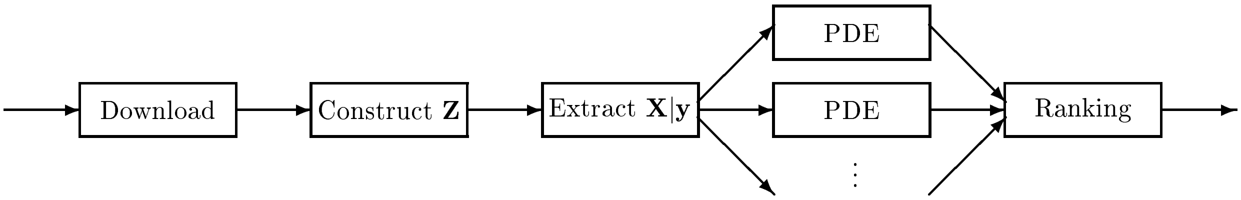


Figure 3: Processing scheme for finding outliers in BrainMap

- Download BrainMap web-page with a Perl/Matlab script.
- Construct a matrix $\mathbf{Z}(N \times P) = [\mathbf{X}, \mathbf{Y}]$ that contains N rows corresponding to $N = 3935$ locations.
- Extract submatrix $\mathbf{X}$ that contains Talairach coordinate for a given phrase.
- Construct probability density estimates (PDE) for each submatrix.
- Rank locations according to their density values.

EXTRACTING LOCATION DATA

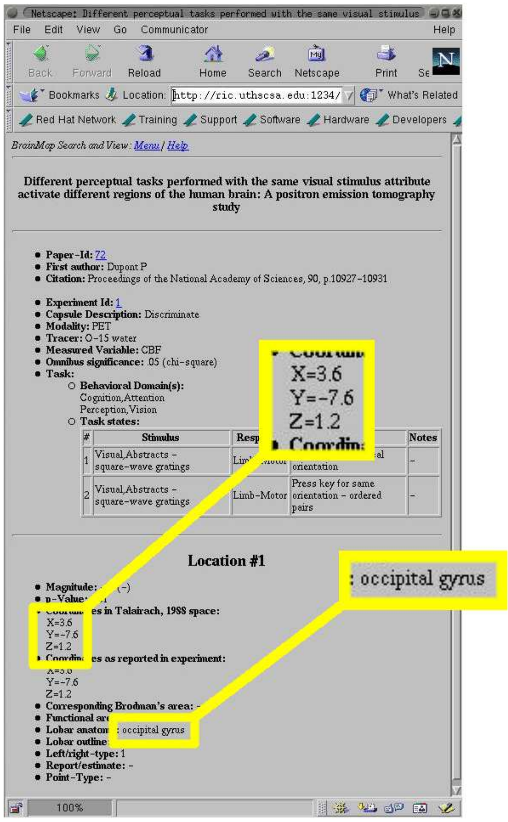


Figure 4: Extraction of data from a "location".

- Extraction of Talairach coordinate. Example (3.6, -7.6, 1.2).
- Extraction of each word and phrase from the field "Lobar anatomy".
- Example "lateral superior parietal" $\rightarrow$ {"lateral", "superior", "parietal", "lateral superior", "superior parietal", "lateral superior parietal"}.
- Multiple data generated for one location.

MODELING THE BRAINMAP "LOCATIONS"

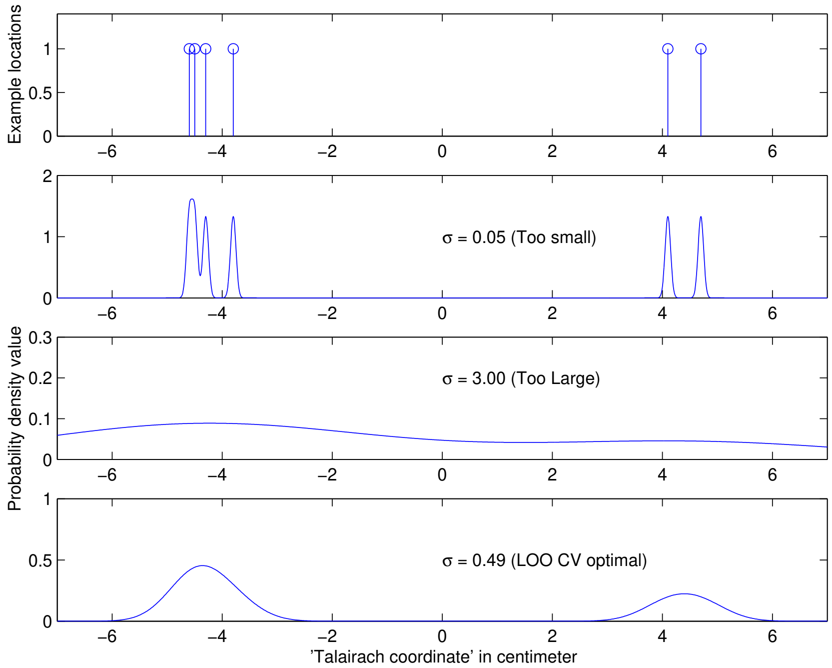


Figure 5: Example of probability density modeling

- Regard the "locations" as being generated from a distribution $p(\mathbf{x}|c)$, where $\mathbf{x}$ lives in 3D Talairach space. c is a word or phrase.
- Models:
  - Simple parametric distribution. Problem with complex distributions, e.g., bimodal.
  - Mixture models. How many components. What width and shape.
  - Kernel method. What width and shape.
  - ...

MODELING OF ANATOMICAL LABELS AND 3D TALAIRACH LABELS

- First try: Finite Gaussian mixture modeled with K determined by AIC and the covariance and center determined on different parts of the data set (Hansen et al., 2000).
- Second try: "kernel methods" (kernels centered on each object: $K = N$) with homogeneous Gaussian kernel

$$\hat{p}(\mathbf{x}) = N^{-1} \sum_{n}^{N} \tilde{p}_n(\mathbf{x}) \tag{1}$$

$$\tilde{p}_n(\mathbf{x}) = (2\pi\sigma^2)^{-3/2} \exp\left(-\frac{1}{2\sigma^2}(\mathbf{x} - \boldsymbol{\mu}_n)^2\right) \tag{2}$$

  Optimize kernel width σ with leave-one-out cross-validation.
- Novelty index from density value.
- Robust estimate of $p(\mathbf{x})$ by excluding the 5% most extreme locations (as determined by their density value) in a two-stage scheme.

PDFS FOR LOCATION LABELS

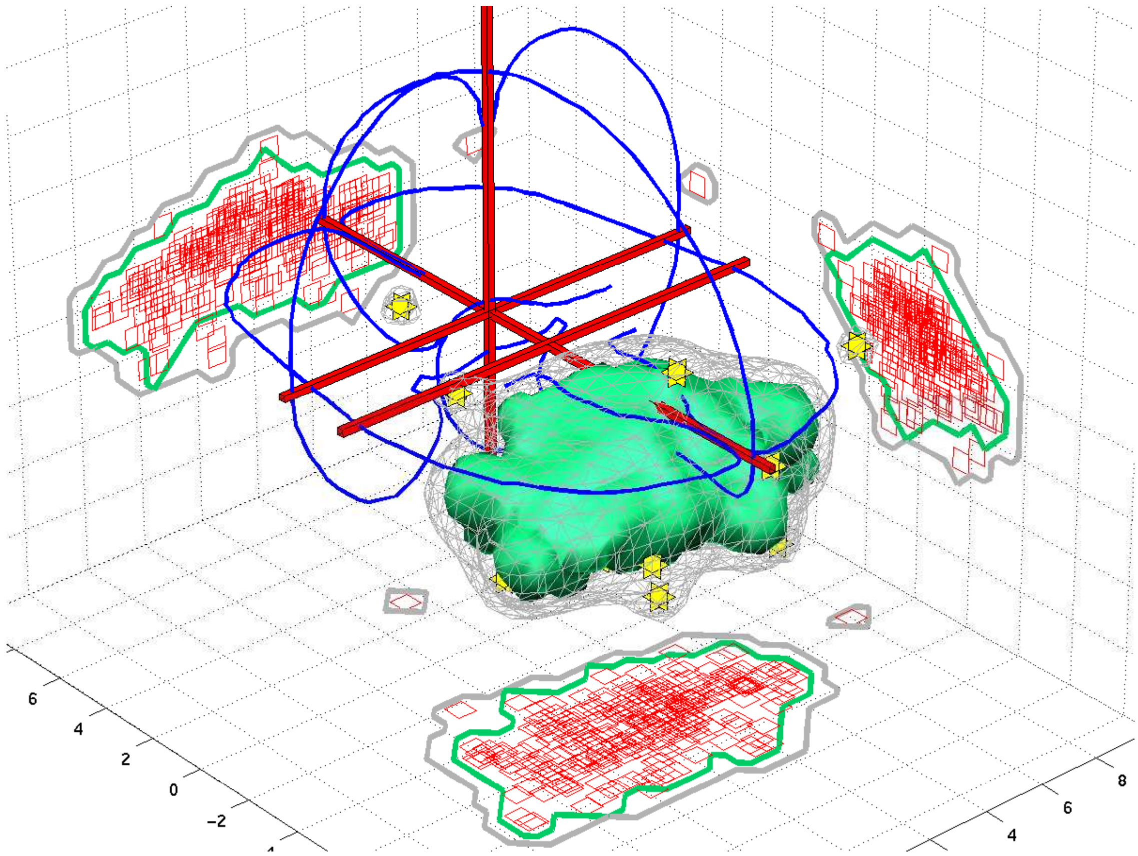
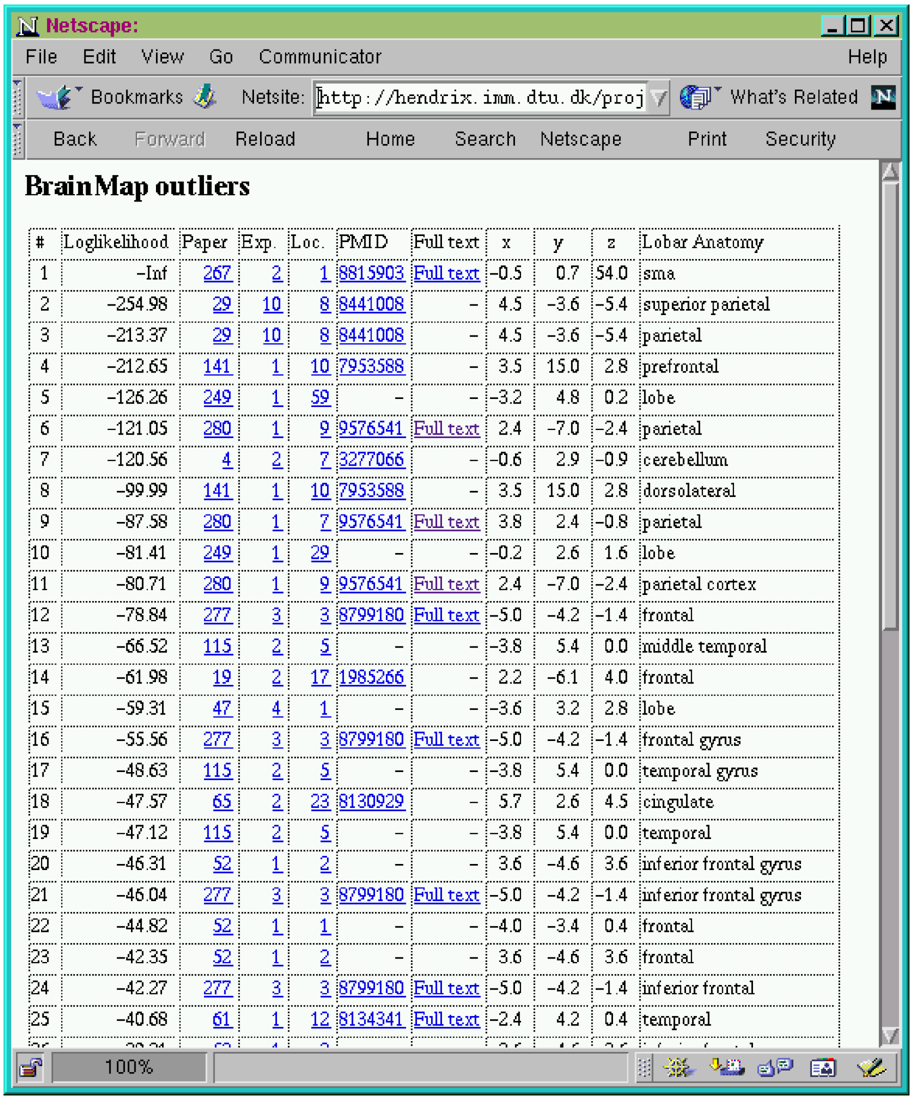


Figure 6: Densities from cerebellum locations. Yellow "points" are the BrainMap locations.

- Condition on anatomical label: $p(\mathbf{x}|c = \text{cerebellum})$.
- Yellow glyphs: Original BrainMap locations.
- Grey wireframe: Isosurface in the first level probability density estimate.
- Green surface: Isosurface in the second level.

RANKING OF OUTLIERS



BrainMap outliers

#	Loglikelihood	Paper	Exp.	Loc.	PMID	Full text	x	y	z	Lobar Anatomy
1	-Inf	267	2	1	8815903	Full text	-0.5	0.7	54.0	sma
2	-254.98	29	10	8	8441008	-	4.5	-3.6	-5.4	superior parietal
3	-213.37	29	10	8	8441008	-	4.5	-3.6	-5.4	parietal
4	-212.65	141	1	10	7953588	-	3.5	15.0	2.8	prefrontal
5	-126.26	249	1	59	-	-	-3.2	4.8	0.2	lobe
6	-121.05	280	1	9	9576541	Full text	2.4	-7.0	-2.4	parietal
7	-120.56	4	2	7	3277066	-	-0.6	2.9	-0.9	cerebellum
8	-99.99	141	1	10	7953588	-	3.5	15.0	2.8	dorsolateral
9	-87.58	280	1	7	9576541	Full text	3.8	2.4	-0.8	parietal
10	-81.41	249	1	29	-	-	-0.2	2.6	1.6	lobe
11	-80.71	280	1	9	9576541	Full text	2.4	-7.0	-2.4	parietal cortex
12	-78.84	277	3	3	8799180	Full text	-5.0	-4.2	-1.4	frontal
13	-66.52	115	2	5	-	-	-3.8	5.4	0.0	middle temporal
14	-61.98	19	2	17	1985266	-	2.2	-6.1	4.0	frontal
15	-59.31	47	4	1	-	-	-3.6	3.2	2.8	lobe
16	-55.56	277	3	3	8799180	Full text	-5.0	-4.2	-1.4	frontal gyrus
17	-48.63	115	2	5	-	-	-3.8	5.4	0.0	temporal gyrus
18	-47.57	65	2	23	8130929	-	5.7	2.6	4.5	cingulate
19	-47.12	115	2	5	-	-	-3.8	5.4	0.0	temporal
20	-46.31	52	1	2	-	-	3.6	-4.6	3.6	inferior frontal gyrus
21	-46.04	277	3	3	8799180	Full text	-5.0	-4.2	-1.4	inferior frontal gyrus
22	-44.82	52	1	1	-	-	-4.0	-3.4	0.4	frontal
23	-42.35	52	1	2	-	-	3.6	-4.6	3.6	frontal
24	-42.27	277	3	3	8799180	Full text	-5.0	-4.2	-1.4	inferior frontal
25	-40.68	61	1	12	8134341	Full text	-2.4	4.2	0.4	temporal

Figure 7: Densities from cerebellum locations.

- Automatic generated list.
- Entries sorted according to novelty.
- 2nd and 3rd entry: More information in a phrase than in a word.

"MANUAL" INVESTIGATION OF OUTLIERS

No.	BrainMap	x	y	z	BrainMap label	Comment	Reference
1	267, 2, 1	−5	7	540	SMA	Millimeter and centimeter for z-coordinate confused during BrainMap entry	(Buckner et al., 1996, table 4, entry 1)
2	29, 10, 8	48	−23	−51	Lateral superior parietal	Resolved: Transcription mistake.	(Corbetta et al., 1993, table 5)
3	141, 1, 10	35	150	28	Dorsolateral prefrontal	Millimeter and centimeter for y-coordinate confused during BrainMap entry	(Kosslyn et al., 1994, table 2, entry 10)
4	249, 1, 59	−31.8	48.1	2.2	Subgyral frontal lobe	Correct	S. K. Brannan, 1997, Unpublished
5	280, 1, 9	24	−70	−24	Dorsal parietal cortex	Is labeled "Right cerebellum" in the article	(Schlösser et al., 1998, table 1, entry 9)
6	4, 2, 7	−6	42	−8	Cerebellum — superior anterior	Not possible to find the foci in the article.	(Petersen et al., 1988)
7	280, 1, 7	38	24	−8	Dorsolateral parietal	Is labeled "Right orbitofrontal cortex" in the article	(Schlösser et al., 1998, table 1, entry 7)
8	249,1,29	−2	26	16	Limbic Lobe	Correct	S. K. Brannan, 1997, Unpublished
9	277, 3, 3	−50	−42	−14	Inferior frontal gyrus, posterior	Is labeled "inferior temporal gyrus posterior (area 37)" in the article	(Owen et al., 1996, table 2, entry 3)
10	115, 2, 5	−38	54	0	Middle temporal gyrus	Not resolved.	(Shaywitz et al., 1995, page 155)
11	19,2,17	24	−47	38	Frontal	Not resolved	(Pardo et al., 1991, Table 1a, entry 17)
12	47,4,1	−36	32	28	Medial frontal lobe	Correct	(George et al., 1994)
13	65, 2, 23	57	26	45	Anterior cingulate	Millimeter and centimeter for x-coordinate confused during BrainMap entry.	(O'Sullivan et al., 1994, table 4, entry 10)
14	52, 1, 2	36	−46	36	Inferior frontal gyrus	Probably misunderstanding of the text during entry. The foci is around supramarginal gyrus and the denoted "BA40".	(Becker et al., 1994, page 287)
15	61, 1, 12	−24	42	4	Temporal/insular	Resolved: Transcription mistake.	(Tulving et al., 1994, table 1)

Table 1: BrainMap outliers. The entries are ordered according to novelty. The second column indicates the paper, experiment and location identifier of the BrainMap database. The third to fifth column are x, y and z with the "reported" coordinates from BrainMap (not the corrected "Talairach 1988" coordinates).

THE WORD "LOBE"

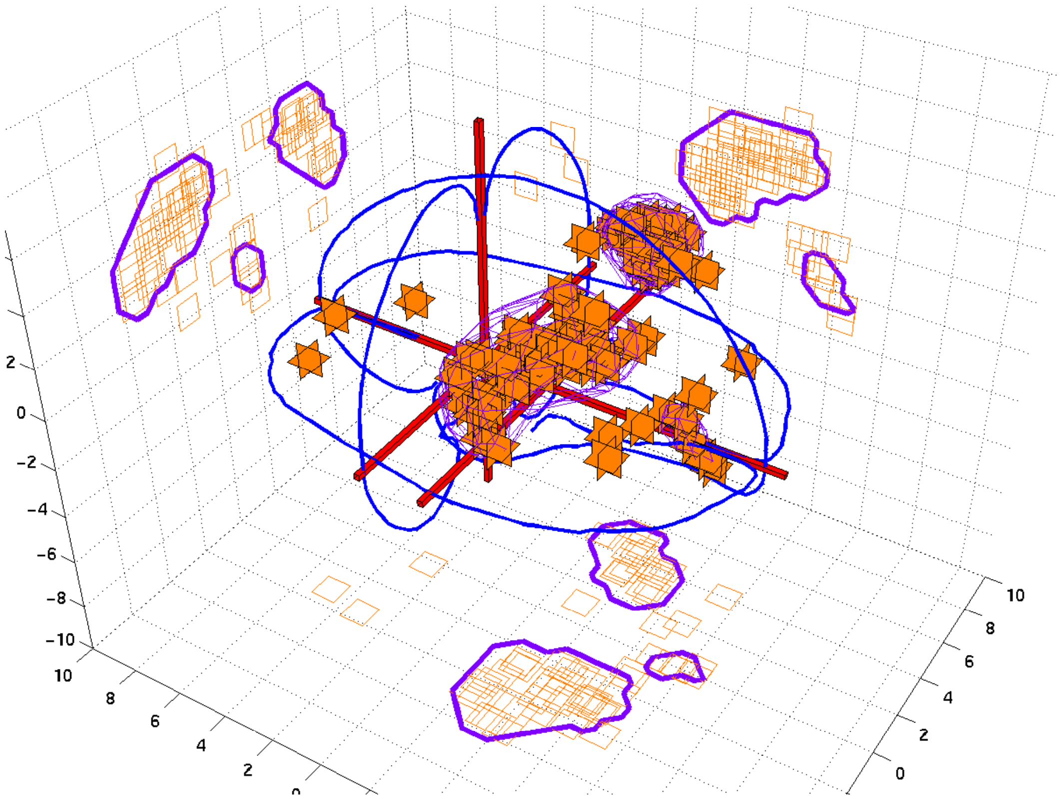


Figure 8: Probability density estimation of "lobe". The blue/magenta wire-frame model is the second stage probability density estimate at a $P_{\mathrm{HPD}} = 0.5$ threshold, and the orange glyphs are the "lobe" BrainMap locations.

Count	Lobar Anatomy
60	inferior parietal lobe
10	superior parietal lobe
6	midline occipital lobe
2	limbic lobe
1	subgyral frontal lobe
1	paracentral parietal lobe
1	medial occipital gyrus/temporal lobe
1	medial frontal lobe

- "Lobe" location is focused in specific areas.

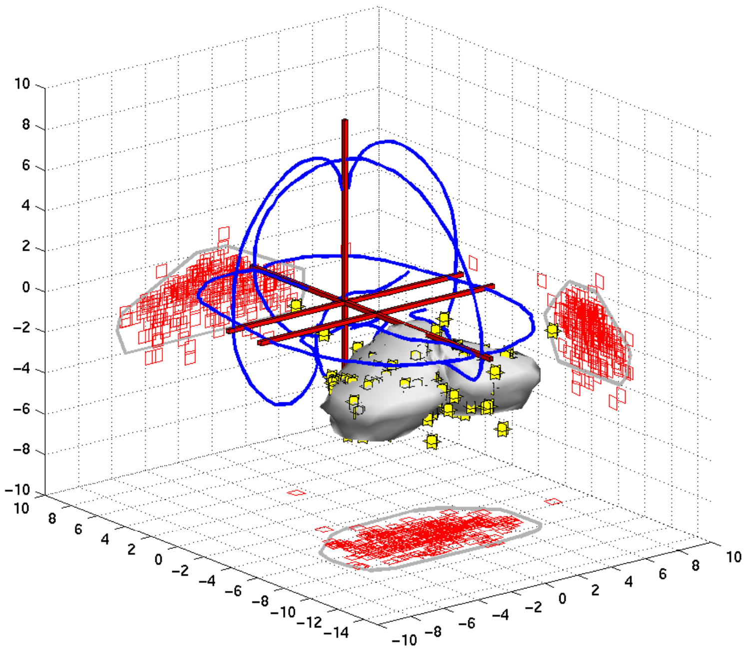


Figure 9: Talairach cerebellum.

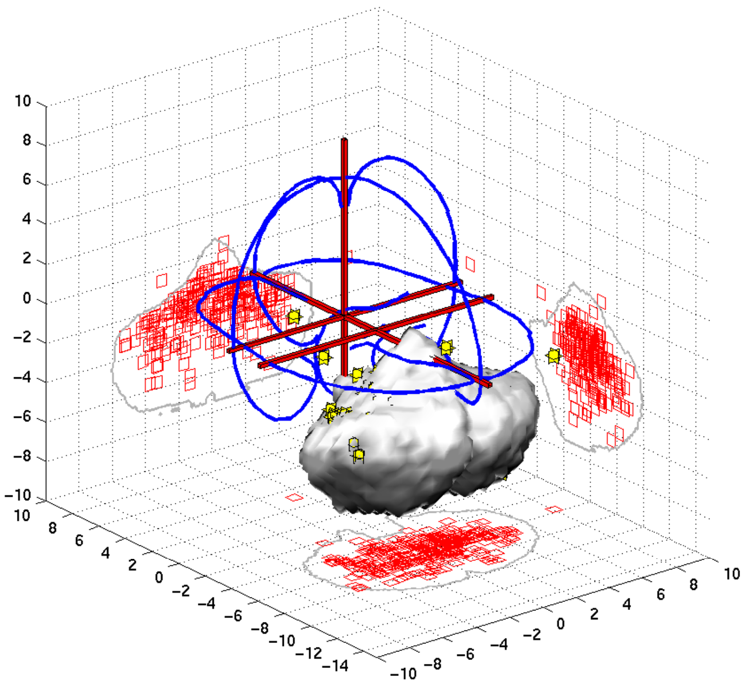


Figure 10: MNI cerebellum.

DENSITIES FOR "BEHAVIOR"

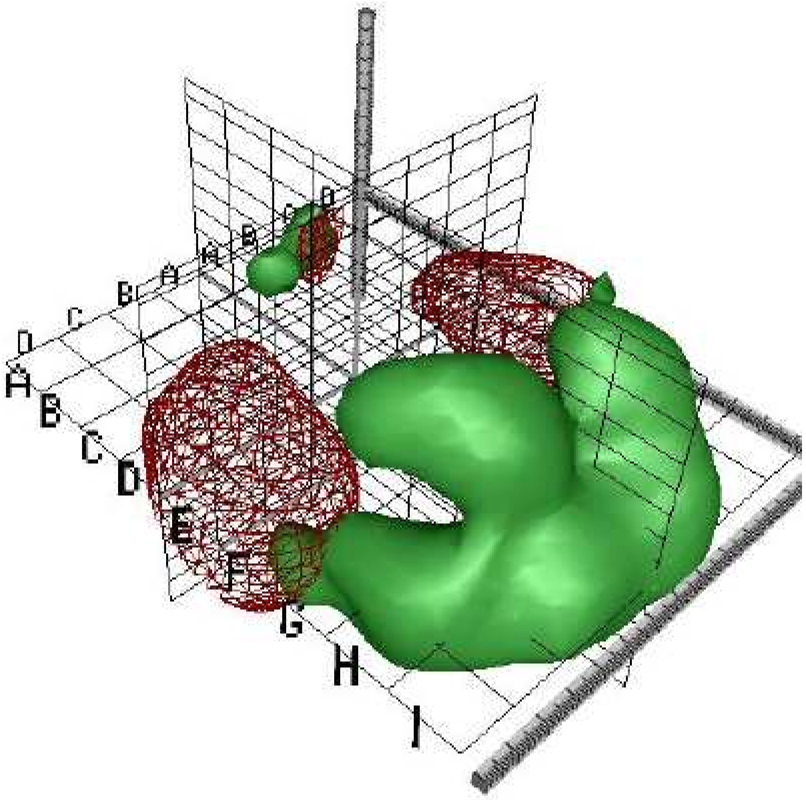


Figure 11: Densities from "Vision" and "Audition" behavioral paradigm.

- Condition on behavior: $p(\mathbf{x}|\text{behavior} = \text{"vision"})$.
- Application? Problem:
  - Behavior annotation is on the level of the experiment
  - Abstract and other bibliographic information are on a yet higher level.
- Applied in single word reading 154 hand picked locations (Turkeltaub et al., 2001).

AUTOMATIC LABELING. PRIOR WORK

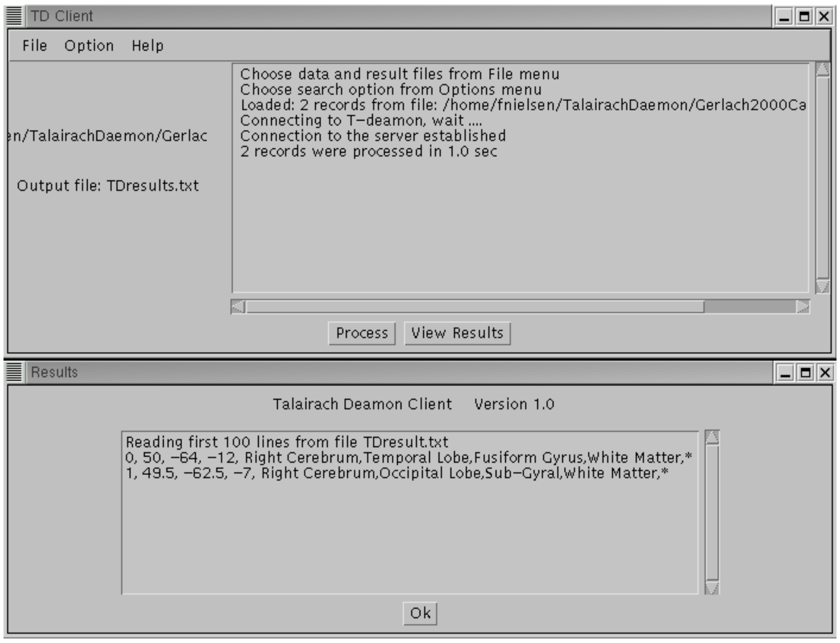


Figure 12: Screenshot from the Talairach Daemon.

- Talairach coordinate → Neuroanatomical label.
- Digital brain atlas based:
  - ANIMAL (Collins et al., 1995).
  - Talairach Daemon based on Talairach and MNI atlas (Lancaster et al., 2000b; Lancaster et al., 1997). Java-based Internet service and stand-alone Java program (Lancaster et al., 2000a).
  - CIeMed (Nowinski et al., 1995) based on Talairach and Schaltenbrand (Schaltenbrand and Wahren, 1977). CD-ROM (Nowinski et al., 1997).
  - Harvard brain atlas (Kikinis et al., 1996) co-registered with MNI (Klein and Hirsch, 2001).

AUTOMATIC LABELING

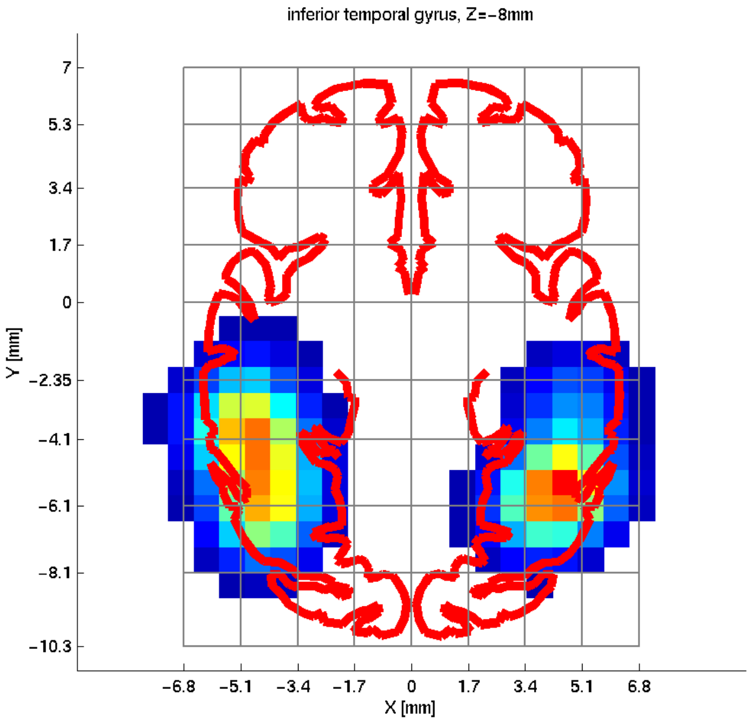


Figure 13: Probability density of "Inferior temporal gyrus".

- Automatic labeling through labeling in the literature via BrainMap.
- Ostensive definition. ("Meaning is use").
- Generate densities for each of anatomical label. Here fixed width kernel density modeling and coarse sampling: 8mm.
- Sort on densities.
- Or generate distribution: $P(\mathbf{x}) = \sum_{p(\mathbf{x}')>p(\mathbf{x})} p(\mathbf{x}')$ and sort that.

AUTOMATIC LABELING: EXAMPLE

Labeler	Label
Christian Gerlach	R. Inferior temporal gyrus
TD (50, -64, -12)	Right Cerebrum,Temporal Lobe,Fusiform Gyrus,White Matter,*
TD (49.5, -62.5, -7)	Right Cerebrum,Occipital Lobe,Sub-Gyral,White Matter,*
TD (50, -64, -12)	Temporal_Lobe 100.00
TD (49.5, -62.5, -7)	Occipital_Lobe 7.70,Temporal_Lobe 62.35

Table 2: An example location: Talairach Daemon labeling. (Gerlach et al., 2000, table 1, entry 1): "R. Inferior temporal gyrus", (50, -64, -12), BA37. Brett's nonlinear transformation: MNI → (Brett) → Talairach: (49.5 -62.5 -7).

Density	P-value	#	Lobar anatomy
12472.34	0.9347557264	5	occipito
10143.67	0.9329029335	37	inferior temporal gyrus
15590.43	0.9264361436	4	occipito temporal
2528.44	0.9163056567	367	inferior
3917.70	0.9075731229	48	ventral
9671.07	0.9026819368	66	inferior temporal
15375.41	0.8024087613	7	ventral surface
15375.41	0.8024087613	7	surface
1200.74	0.7883446267	762	gyrus
9475.11	0.7713286841	22	inferior occipital
3607.68	0.8635240291	48	ventral
16900.23	0.8544980115	3	inferior temporal gyrus posterior
2091.93	0.8438028002	367	inferior
20796.17	0.8273447873	5	inferior lateral
8450.12	0.8225637414	6	temporal gyrus posterior
1862.94	0.8083775236	99	lateral
7395.51	0.7818767138	37	inferior temporal gyrus
6982.64	0.7533701307	66	inferior temporal
8632.66	0.7106316973	22	inferior occipital
7242.96	0.6965897412	7	gyrus posterior

Table 3: An example location: Labeled through BrainMap. With Brett's transformation above the line. # is the number of locations defining the volume.

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