Bibliography of Segmentation in Neuroimaging

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Abstract

Reference for segmentation in neuroimaging are collected. Both tissue segmentation and parcellation is included.

This structured bibliography is part of a larger collection of bibliographies see http://www.imm.dtu.dk/˜fn/bib/Nielsen2001Bib/. The bibliography is written in LaTeX and BIBTeX and should be available both as HTML and PostScript.

The bibliography is probably far from complete, but new references are added whenever the author finds new material and has the time to add them. You can email the author if corrections are required or you have found some reference that you fell ought to be included: fn@imm.dtu.dk.

Thanks to Jürgen Hänggi, Jonathan Bailleul and Arno Klein who provided information. Much of the information in this bibliography is from the SPM mailing list posted by numerous researchers.

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1 General references

A list of references is available from http://neuro-www.mgh.harvard.edu:16080/cma/seg/references.html

1.1 Unclassified

(Harris et al., 2001) parcellation of cortex with brain warping and manual atlas. PMID: 8978636, PMID: 9786148, PMID: 11185422

B. Dawant, S.L. Hartmann, J.-P. Thirion, F. Maes, D. Vandermeulen, P. Demaerel, Automatic 3-D segmentation of internal structures of the head in MR images using a combination of similarity and free-form transformations : part I, methodology and validation on normal subjects , IEEE transactions on medical imaging, vol. 18, no. 10, pp. 909-916, October 1999

2 Inhomogeneity correction

MRI intensity non-uniformity (intensity inhomogeneity) can have a substantial impact on the performance of the segmentation results (Sled et al., 1997a) and the image should be bias field corrected. Table 1 shows a number of the tools in use. (Ashburner and Friston, 1998) describes a combination of tissue classification with inhomogeneity correction.

(Arnold et al., 2001; Schaper et al., 2001) compared six algorithms for inhomogeneity correction (N3, hum, eq, bfc, cma and SPM99). (Boyes et al., 2008) investigated the performance of the N3 program on scans from 3T scanners. Other references in relation to bias field estimation are (Guillemaud and Brady, 1997) and a review (Hou, 2006).

Name	Method and Description	References
cma		Center for Morphometric Analysis, Massachusetts General Hospital
EMS *	Polynomial basis functions. Part of segmentation program	(Van Leemput, 2001, p. 15–19), (Van Leemput et al., 1999a)
eq		(Cohen et al., 2000)
FAST *	"FMRIB's Automated Segmentation Tool". A segmentation tool including inhomobeneity correction	http://www.fmrib.ox.ac.uk/fsl/fast-/index.html
FreeSurfer *	Implemented in the `mri_normalize` program. Can be executed from `csurf` GUI.	(Dale et al., 1999; Fischl et al., 1999a; Fischl et al., 1999b; Fischl and Dale, 2000; Fischl et al., 2001; Busa, 2002) http://surfer.nmr.mgh.harvard.edu/
hum		(Brinkmann et al., 1998)
ITK *	The "itk::MRIBiasFieldCorrectionFilter" class in the National Library of Medicine Insight Segmentation and Registration Toolkit (ITK) based on Legendre polynomial	http://www.itk.org-/HTML-/MRIBiasCorrection.htm, (Styner et al., 2000; Styner and Gerig, 1997)
N3 *		(Sled et al., 1998; Sled et al., 1997b; Sled, 1997), http://packages.bic.mni.mcgill.ca/, http://www.bic.mni.mcgill.ca-/software/N3/
PABIC *	"PArametric BIas field Correction". Included in ITK.	(Styner et al., 2000; Styner and Gerig, 1997)
SPM *		(Ashburner and Friston, 2000)
SPM2 *	Available in the functions with prefix `spm_bias_`	(Ashburner, 2002), Early version: ftp://ftp.fil.ion.ucl.ac.uk/spm/flatten
vol_homocor.m *	Program by Gary Glover distributed by Kalina Christoff	http://www-psych.stanford.edu/~kalina/SPM99-/Tools/vol_homocor.html

Table 1: MRI Inhomogeneity correction tools.

3 Stripping

The process of "stripping", "skull-stripping", "brain/non-brain segmentation", "brain surface extraction", "brain extraction" or "brain extraction algorithms (BEA)" removes the skull, scalp and meninges and maintains the "brain" which usually includes white and grey matter as well as CSF (at least the ventricular CSF). Table 2 is a list of the tools for this operation. A study showed that McStrip was much slower than BSE and BET, but that it was the most precise (Boesen et al., 2003). In a comparison BET, 3dIntracranial, HWA and BSE against a manual stripping as gold standard "BSE tended to perform best" and "HWA and BSE were more robust across diagnostic groups" (Fennema-Notestine et al., 2006). Another algorithm is described in (Atkins and Mackiewich, 1998).

One study found that in voxel-based morphometry (VBM) using SPM2 brain extraction would profoundly affect the results (Fein et al., 2006).

Table 2: Stripping

Name	Impl.	Description	Reference
3dIntracranial *		Brain extraction included in AFNI	(Ward, 1999), http://afni.nimh.nih.gov/afni/-doc/help/3dIntracranial.html
BEMA		"Brain extraction meta-algorithm"	(Rex et al., 2004)
BET *		"Brain Extraction Tool" by Stephen Smith. Conveniently included in FSL, MRIcro and mri3dX	(Smith, 2002; Smith, 2000), http://www.fmrib.ox.ac.uk/fsl/bet/, MRIcro: http://www.psychology.-nottingham.ac.uk/staff/cr1-/mricro.html
BSE *		"Brain Surface Extraction"part of BrainSuite. Interactive GUI version exists with the X/Motif-based xbse	(Shattuck et al., 2001; Sandor and Leahy, 1997), http://neuroimage.usc.edu/BSE/
McStrip *	IDL, C	"Minneapolis Consensus Strip" (MCS). Consensus/hybrid based method relying on AIR5.0 and BSE	(Rehm et al., 2004; Rehm et al., 1999), http://www.neurovia.umn.edu-/incweb/McStrip_download.html
MIPAV *	Java		(Bazin et al., 2007; Goldszal et al., 1998), http://mipav.cit.nih.gov/
FreeSurfer *		Can be executed from `csurf` GUI.	(Dale et al., 1999; Fischl et al., 1999a; Fischl et al., 1999b; Fischl and Dale, 2000; Fischl et al., 2001; Busa, 2002) http://surfer.nmr.mgh.harvard.edu/
HWA *		Hybrid Watershed algorithm in FreeSurfer	(Segonne et al., 2004)

4 Brain tissue segmentation

Brain tissue segmentation typically classifies voxels into grey matter, white matter, CSF and "non-brain". Some segmentations works with a further "lesion" class.

4.1 Methods for segmentation

Many papers describe methods for brain tissue segmentation, and just a few are listed in Table 3. Others are (Cocosco et al., 2002; Sun and Wang, 2005).

Table 3: Methods for segmentation.

Description	Reference
Use of atlas prior (tissue probability maps in stereotaxic space)	(Kamber et al., 1995)
Input as T1, T2, PD and output as GM, WM, CSF. Selection of a training classes for the segmentation	(Harris et al., 1999)
Input as T1, T2, PD and output as WM, GM, CSF, outliers. With inhomogeneity correction and atlas prior. Gaussian mixture estimated robustly. Lesions detected as outliers. Bias field modeled with polynomials. Markov random field for prior volumes	(Van Leemput et al., 2001; Van Leemput et al., 2000)
K-Nearest Neighbor on data from five types of regular MRI-scans for classification of white matter lesions	(Anbeek et al., 2003)
"Fuzzy inference system" on 3 different MR images for classifying white matter hyperintensity	(Admiraal-Behloul et al., 2005)
Support vector machine on 4 different MR images for white matter lesion segmentation	(Lao et al., 2006)

A "ground truth" makes it possible to evaluate the performance of the segmentation algorithm. (Moretti et al., 2000) took this approach with the use of the BrainWeb labeled brain as ground truth.

4.2 Tools

Table 4: Tools for segmentation

Name	Input	Output	Description	Reference
BrainSeg				Ali Hojjat
EMS			'Expectation-Maximization Segmentation' implemented as an SPM plugin	(Van Leemput et al., 2001; Van Leemput et al., 1999b; Van Leemput et al., 1999a; Maes et al., 1997; Van Leemput et al., 2000) http://bilbo.esat.kuleuven.ac.be-/web-pages/downloads/ems-/ems.html
FAST *		GM, WM, CSF, ...	FMRIB's Automated Segmentation Tool, Hidden Markov model with inhomogeneity correction	(Zhang et al., 2001a; Zhang et al., 2000; Zhang et al., 2001b) http://www.fmrib.ox.ac.uk-/fsl/fast/

Name	Input	Output	Description	Reference
INSECT			GM, WM and CSF segmentation with an artificial neural network with 9-parameter spatial normalization	(Kollokian, 1996; Collins et al., 1994)
IRIS *			Visualization program with manual drawing by Guido Gerig and Sean Ho. One of the versions is called IRIS2000	http://www.cs.unc.edu/~ruffin/-iris/
MIDAS (Freeborough)			"Medical Image Display and Analysis Software". Interactive Unix/X program, with thresholding, region growing and morphological operations	(Freeborough et al., 1997)
SEAL			"Sulcal Extraction and Automated Labelling"	(Goualher et al., 1999)
SEGRAS		WM, GM, CSF, Lesion	Trained artificial neural network used as classifier	Alan Rene Rasmussen, Hvidovre Hospital
SPM *			Segments into GM, WM, CSF and other. Implemented in versions SPM99 and SPM2.	(Ashburner and Friston, 1997; Ashburner and Friston, 2000; Ashburner and Friston, 2003)
SPM5 *			Segmentation with image registration and bias correction	(Ashburner and Friston, 2005)
—			Combined manual/automatic	(Zavaljevski et al., 2000)

4.3 Labeled brains

Probalistic volumes for background, CSF, grey matter, white matter, fat, muscle/skin, skin, skull, glial matter, and "connective" are available in connection with the BrainWeb web-service/database from the URL http://www.bic.mni.mcgill.ca/brainweb/anatomic_normal.html (Cocosco et al., 1997).

"ICBM tissue probabilities" with gray matter, white matter and CSF are available from http://www.loni.ucla.edu/ICBM/ICBM_TissueProb.html

The *Internet Brain Segmentation Repository* (IBSR), http://www.cma.mgh.harvard.edu/ibsr/, has simulated and real MRI data with gray/white/other expert segmentations.

Gray, white and CSF and brain mask are also distributed with the SPM2 package (in the `apriori` subdirectory).

5 Cortical surface extraction

"Cortical surface extraction" or "Cortical surface reconstruction".

The "marching cubes" algorithm (Lorensen and Cline, 1987) can extract the cortical surface but usually with a bad results, e.g., not necessarily topologically correct. The algorithm is implemented in Matlab, IDL, VTK and polyr (Jensen, 1995; Nielsen, 1998).

(Mohlberg and Zilles, 2000) obtains somewhat better results by combining surface warping, marching cubes and a fluid membrane model. (Zeng et al., 1999; MacDonald et al., 2000) use coupled inner and outer surface of the cortex. (Goldenberg et al., 2002) describes an other method. None of these seem to be publicly available. The MacDonald program seems to be available internally at MNI and able to handle MINC files, see http://www.bic.mni.mcgill.ca/˜david/FAQ/How_to_extract_cortical_surfaces.txt.

FreeSurfer traces the white matter (Dale et al., 1999). A poor man's method with a MRI T1 along this line is first to do skull-stripping, then threshold on a sufficiently high value to only incorporate the white matter and lastly make an ordinary marching cubes. (Schaper et al., 2006) perform a quantitative comparison between four of the algorithms.

Table 5: Cortical surface extraction

Name	Impl.	Description	Reference
BrainVisa			(Cointepas et al., 2001)
BrainVoyager			http://www.brainvoyager.com
FreeSurfer *		Can be executed from `csurf` GUI.	(Dale et al., 1999; Fischl et al., 1999a; Fischl et al., 1999b; Fischl and Dale, 2000; Fischl et al., 2001; Busa, 2002) http://surfer.nmr.mgh.harvard.edu/
Geometrical Atlas Visualizer	MacOS	Visualization of the cortical surface on a disc and where the principal sulci and landmarks are aligned with the the axes.	(Toro, 2003), http://www.snv.jussieu.fr-/insermu483/geometricatlas/
IsoSurf *		Isosurface	http://svr-www.eng.cam.ac.uk-/˜ gmt11/software/isosurf/isosurf.html
Polyr *	C	Marching cube	(Jensen, 1995; Nielsen, 1998) , http://hendrix.imm.dtu.dk/software/
SureFit *			http://brainvis.wustl.edu/-resources/surefitnew.html/
SurfRelax *			(Larsson, 2001), http://www.cns.nyu.edu-/˜jonas/software.html

5.1 Flattening

After extraction of the surface algorithms can smooth it, into a sphere or cut and flatten it (unfold it) (Sherk, 1992; Carman et al., 1995; Van Essen and Maunsell, 1980; Jouandet et al., 1989). Several of the tools in Table 5 have these capabilities.

Table 6: Flattening algorithms

Name	Impl.	Description	Reference
DMflatten			(Balasubramanian et al., 2005; Balasubramanian et al., 2006)
mrFlatMesh	Matlab	Companion to mrGray	A. R. Wade

6 Parcellation

IBASPM ("Individual Brain Atlases using Statistical Parametric Mapping software" , http://www.thomaskoenig.ch/Lester/ibaspm.htm) is an SPM2 plugin that utilizes the normalization and brain tissue segmetation parts of SPM2 together with the AAL atlas for the construction of parcellation of the brain in individuals. Programs by Claus Svarer and others (http://nru.dk/software/) provide similar capabilities (Svarer et al., 2005; Svarer et al., 2002) using, e.g., MRIWarp (Kjems et al., 1999a; Kjems et al., 1999b)

Rview contains a number of interactive drawing functions http://www.colin-studholme.net/software/software.html

(Schleicher et al., 1999; Schleicher et al., 2000; Schmitt et al., 2003) describe methods for parcellation based on cytoarchitectonics. Macaque cortex parcellation based receptor binding density across multiple ligands is performed with different multivariate analysis techniques in (Kötter et al., 2001).

6.1 Tools

Table 7: Parcellation tools

Name	Description	Reference
ANIMAL	'Automatic Non-linear Image Matching and Anatomical Labeling' Nonlinear warping and labeling by a previous labeled volume	(Collins et al., 1995), http://www.bic.mni.mcgill.ca/users-/louis/MNI_ANIMAL_home/readme/ ?
Mindboggle	Automatic labeling based on 20 labeled templates	(Klein et al., 2005; Klein and Hirsch, 2005; Klein and Hirsch, 2001)
pveout	Nonlinear alignment with MRIWarp to 10 different labeled templates	(Svarer et al., 2005)

Table 8: Mask and region tools

Name	Description	Reference
SimpleROIBuilder	SPM2 and SPM5 toolbox	http://www-personal.umich.edu-/~rcwelsh/SimpleROIBuilder/
SPM Anatomy toolbox		http://www.fz-juelich.de/ime-/spm_anatomy_toolbox

6.2 Labeled brains

Table 9: Labeled brains. The second column with the '#' heading indicates the number of labels. '*' denotes that the labeled brain is readily available on the Internet. Entries above the line is digitized and paper atlasses are below the line.

Name	#	Description	Reference
AAL		See Tzourio-Mazoyer	

Name	#	Description	Reference
Brodmann *	41+1	Brodmann areas. Non-space filling, non-probabilistic.	Van Essen, Drury. Included in MRIcro as `brodmann.hdr/brodmann.img(.gz)`
CBA	"almost 400"	Atlas incorporated in a commercial program. "Greitz atlas". Brodmann areas, gyri, central structures	(Applied Medical Imaging, 1994; Seitz et al., 1990; Greitz et al., 1991; Thurfjell et al., 1994; Thurfjell et al., 1995; Bohm et al., 1986; Bohm et al., 1989; Bohm et al., 1991; Bohm et al., 1985)
Cerefy		Commercial digitized versions of the Talairach and Schaltenbrand atlases and Windows/MacIntosh program.	(Nowinski et al., 2001; Nowinski et al., 1997; Nowinski et al., 1995b; Nowinski et al., 1995a)
Hammers 2002	2 × 19 + 3(?), 43	Segmentation of MNI single subject Non-probabilistic, space-filling, Non-hierarchical.	(Hammers et al., 2002)
IBSR "18"	43	"18 Scans: T1-weighted MR Image data with expert segmentations of 43 individual structures"	http://www.cma.mgh.harvard.edu-/ibsr/data.html
ICBM label *(?)	58(?)	ICBM Single subject MRI anatomical template. Distributed in Minc format (`ICBM_labels.mnc` and `ICBM_1.0mm_label.mnc`). Almost space-filling. Non-hierarchical.	http://www.loni.ucla.edu-/NCRR/Software-/ICBM_Template.html, Label names: http://www.loni.ucla.edu-/NCRR/Software-/ICBM_Template-/Templat_Labels.htm
ICBM Kabani	90/91(?)	Parcellation of MNI single subject in accordance with NeuroNames	(Kabani et al., 1998)
'Iowa' (frontal)	11	Parcellations of the frontal cortex by two human raters	(Crespo-Facorro et al., 1999)
'Iowa' (temporal)	16	Parcellation of the temporal neocortex	(Kim et al., 2000)
'Iowa' (cerebral cortex)	41		(Crespo-Facorro et al., 2000)
Mindboggle *	?	Based on 10–20 subjects. Previously 'The Whole Brain Atlas' transformed to MNI-space	(Klein and Hirsch, 2005; Klein and Hirsch, 2001; Klein and Hirsch, 2002; Kikinis et al., 1996), http://www.binarybottle.com-/mindboggle.html
MNI SPAM	91	Probabilistic volumes in MNI-space	(Evans et al., 1996; Collins et al., 1999)
Jerne, "Volumes of Interest") *	100+	MNI-space, probabilistic, space-filled, hierarchical. Approximate volumes based on labeling in the BrainMap database.	(Nielsen and Hansen, 2002), http://hendrix.imm.dtu.dk-/services/jerne/ninf/voi.html

Name	#	Description	Reference
PMaps *	18	Probability map of selected cytoarchitectonic areas from Jülich: 1, 3a, 3b, 4a, 4p, 6, 17 (V1), 18 (V2), 41, 44, 45	(Eickhoff et al., 2005c; Eickhoff, 2005; Geyer et al., 1996; Amunts et al., 1999; Amunts et al., 2000; Morosan et al., 2001; Rademacher et al., 2001; Amunts et al., 1998; Morosan et al., 1996; Eickhoff et al., 2005b; Eickhoff et al., 2005a), http://www.fz-juelich.de/ime/spm_anatomy_toolbox, http://www.fz-juelich.de/ime-/ProbabilityMaps_eng.html
Svarer *	$2 \times 17 + 1$	10 subjects labeled in native space	(Svarer et al., 2005; Svarer et al., 2002), http://nru.dk/software/
Talairach Daemon *		A program that contains two brain templates: A digitized Talairach atlas and MNI	(Lancaster et al., 2000b; Lancaster et al., 1997a; Lancaster et al., 1997b; Lancaster et al., 2000a). The labeling is used by the WFU PickAtlas program.
Tzourio-Mazoyer *	2×45(?), 116	MNI-space, non-probabilistic, non-space filled, semi-hierarchical. This is sometimes referred to as "automated anatomical labeling" or "AAL". The labeled volume is distributed with MRIcro has 116 different labels	(Tzourio-Mazoyer et al., 2002a; Tzourio-Mazoyer et al., 2002b), http://www.cyceron.fr/freeware/. The labeled volume is distributed with MRIcro as aal.hdr/aal.img(.gz) and aal.txt
VOXEL-MAN	?	Commercial program with atlas	(Höhne et al., 1992; Höhne, 1997; Höhne, 2001)
Brodmann		Book with simple drawings of cytoarchitectonic areas.	(Brodmann, 1994)
			Duvernoy 1992
Mai		Book with labeled brain in stereotaxic space	(Mai et al., 1997)
Ono		Book that describe sulcal variability	(Ono et al., 1990)
Schaltenbrand		Book	(Schaltenbrand and Wahren, 1977)
			Szikla et al. 1977
Talairach	'Many'	Book with a labeled brain in stereotaxic space	(Talairach and Tournoux, 1988; Talairach and Szikla, 1967)

Anatomical labeled brains in stereotaxic coordinates can form the basis for automatic labeling new brains and coordinates. A bibliography on brain atlases is also available at http://www-iasc.enst-bretagne.fr/PROJECTS/ATLAS/atlas-dss.biblio.html. Early swedish effort is documented in (Bohm et al., 1985; Bohm et al., 1991; Greitz et al., 1991; Greitz et al., 1995). Early montrealean in (Evans et al., 1988; Evans et al., 1991).

Brodmann area labeling has been developed using descriptions from the Caret package on the Colin27 atlas and a cortical surface matching method (Rasser et al., 2004): Individual subject's structural MRI are deformed to an atlas.

An Internet service with the MNI SPAM probability volumes was announced with (Kim et al., 2002) with the URL http://nm.snu.ac.kr/SPAM/ but it does not seem to work.

6.3 Unclassified

(Bajcsy et al., 1983; Bailleul et al., 2004)

Comput Med Imaging Graph 1994 Nov-Dec;18(6):413-22 Computerized localization of brain structures in single photon emission computed tomography using a proportional anatomical stereotactic atlas. Migneco O, Darcourt J, Benoliel J, Martin F, Robert P, Bussiere-Lapalus F, Mena I. PMID 7850735

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