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neuGRID

A GRID-BASED e-INFRASTRUCTURE FOR DATA ARCHIVING/ COMMUNICATION AND COMPUTATIONALLY INTENSIVE APPLICATIONS IN THE MEDICAL SCIENCES

Combination of Collaborative Project and Coordination and Support Action

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of Contents:

Executive summary

This document, *D5.1 Brain Imaging Service Portfolio Specification*, describes the brain imaging services that NeuGRID aims to deliver to its end users. Specifically, this document lists the library of image processing and statistical analysis tools and algorithms that will be available to neuGRID users for use as-is or for use as modules in user-generated pipelines or workflows.

As the description of these services is to a large extent dependent on the completion of the NeuGRID User Requirements Specification (Deliverables D9.1 and D9.2) which are not due until later in the project, future releases of this document may be necessary.

Introduction

The primary goal of NeuGRID is to enable neuroscientists to perform sophisticated analyses on neuro-imaging data through an intuitive, web-based, grid-enabled platform. Using neuGRID and its underlying components, scientists will be able to perform image processing and analysis tasks that are currently typically performed at large, established brain imaging centres. In other words, NeuGRID aims to bring the brain image analysis centre "home" to the user, obviating the need for local hardware, software and, to some extent, related expertise. Central to this goal is the portfolio of brain image analysis services offered by NeuGRID, describing what brain imaging analysis tools NeuGRID will be able to provide to its end users.

The Brain Imaging Services broadly fall into the following three categories:

- Data and workflow management

  This includes data collection, anonymization, identification, storage, and curation, as well workflow generation and execution. Since these aspects are more of logistical nature and/or not brain-imaging-specific as opposed to end-user brain imaging services, they will not be further developed here. These services are more extensively covered in -primarily- Workpackage 6.

- Image processing

  This includes a library of image processing algorithms focused on manipulating the source images so as to ultimately extract features of the images which can be used in a variety of statistical analyses. Examples of this are the spatial normalization and blurring operations necessary to perform so-called Voxel-Based Morphometry (VBM); the registration and surface extraction algorithms used in the estimation of cortical thickness (e.g., the CLASP algorithm [8]); or the registration and voxel classification algorithms used in brain tissue identification.

- Statistical analysis

  This includes any statistical analyses performed on data, be they "raw" (unprocessed) source data or – more likely – data processed using the library of methods covered under "Image processing."

It should be understood that this is a rough categorization only and that occasionally it may be arguable which category a particular technique belongs to. For instance, smoothing (blurring) of the image data with a particular filter prior to performing statistical analyses would is considered part of "image processing" by some, and an element of "statistical analysis" by others.

Methodological approach

During the first year of the Project, work in Workpackage 9 focused on user requirements elicitation through a number in-person as well as telephone meetings with (primarily) potential end-users: scientists and students at the three hospitals participating in the Project (P1 FBF Brescia, P5 VUmc Amsterdam, P6 KI Stockholm). These sessions have resulted in, among other things, an extensive list of software tools and algorithms desired by the scientists in question. This document is to a large part derived from this aspect of the User Requirements Specification effort.

As mentioned before, at the time of writing of this deliverable, the user requirements work has not been completed which may require subsequent versions of this deliverable to be generated. Specifically, the scope of the end-user brain imaging services that the neuGRID infrastructure in principle *could* provide is limitless, which means that a prioritization needs to be carried out to determine which services can feasibly be implemented during the course of the project. This prioritization work is currently underway across the neuGRID consortium and will be made available in the User Requirements Specification deliverables (D9.1 and D9.2).

In this deliverable a fairly exhaustive list of brain imaging tools identified by the user community will be presented with an initial prioritization, but this will likely need to be revised during the second year of the project as the project-wide prioritization effort continues. In this document, the tools are identified as the essential "Tier 1", which covers tools part of/necessary for running the cortical thickness extraction algorithm "CLASP" [8], identified as a test bed and minimum requirement for neuGRID, and everything else ("Tier 2").

Activity carried out and results

Part of the extensive user requirements elicitation effort has resulted in a list of potential "pipelines" desired by the user communities of the neuGRID clinical centres P5 VUmc Amsterdam, P6 KI Stockholm, and P1 FBF Brescia (table shared with D10.1 and to be further detailed in D9.1):

Institute	Image Processing Tools	(Statistical) Analysis Tools
VUmc	fMRIB Software Library (FSL): Flirt, Fnirt, FDT, FAST, Melodic (visualization tool), Siena, XSiena, FEAT, http://www.fmrib.ox.ac.uk • MRIcro, Brain Extraction Tool (BET), http://www.sph.sc.edu/comd/rorden/mricro.html • Montreal Neurological Institute (MNI) (BIC Tools & Software – The Brain Imaging Software Toolbox): N3. http://www.bic.mni.mcgill.ca/software/ • BioInformatics Research Network (BIRN) (Gradiant Non-Linearity Distortion Correction): Gradient non-linearity. http://www.nbirn.net/ • DRG Fluid. • Generic: o Image calculations (adding subtracting, multiplying etc) o Morphological operations on images o File format conversions	Statistical Parametric Mapping – SPM http://www.fil.ion.ucl.ac.uk/spm/software/
KI	• MNI BIC Tool – CIVET Pipeline http://wiki.bic.mni.mcgill.ca/index.php/CIVET , • FSL, • Brainvoyager http://www.brainvoyager.com/ • Matlab http://www.matlab.com , • Analysis fo Functional NeuroImages (AFNI), http://afni.nimh.nih.gov/afni/ • E-prime http://www.pstnet.com/ and • Statistica.	Hermes (Hermes Medical) B-MAP (Pipeline 1 and Pipeline 2) http://www.hermesmedical.com/

FBF	• FSL Tools fMRIB's Diffusion Toolbox FDT 2.0, Melodic
	• MNI BIC Tools:
	  • Display, register, Brainsuite
	• LoNI http://www.loni.ucla.edu/Software/ tools:
	  • Dual_warpe_warpcurve, Decoder_blend_all, mk_seg16bit, mk_gray, add_gray_to_inflated_LEFT1, add_gray_to_inflated_RIGHT1, pmap_apeVSctrl, make_UVL_*; 1st_script_tracer_avg_DIAG; 2nd_script_core_test_L_DIAG; 2nd_script_core_test_R_DIAG; Pmap_DistCore_DIAG
	• MRIcro (MRIcro) (visualization)
	  • BET Function
	• IdeALab Tools (IdeALab) http://neuroscience.ucdavis.edu/idealab/software/index.php
	• Image Conversion software
	  • MRIconverter
	  • dcm2nii
	• New Promising Tools:
	  • 3D Slicer, VTK, Freesurfer, MPIAV, NA-MIC Kit components, MED-INRIA, BrainVoyager, BrainMAP
		• SPSS http://www.spss.com/,
		• Statistical Parametric Mapping – SPM, Matlab, Quanta 6.1
		• R (R) http://www.r-project.org
		• Statistical Parametric Mapping – SPM

Although this covers a wide range of toolkits, there is some overlap between these wish lists, as shown in this table from D10.1:

	FSL	MNI/BIC	LoNI	SPM	MRIcro/BET	SPSS	HERMES	Idealab	Matlab	R	AFNI	E-Prime	Statistica	DRG	BIRN	BrainVoy.	QUANT
VUmc	X	X		X	X									X	X		
KI	X	X					X		X		X	X	X			X	
FBF	X	X	X	X	X	X		X	X	X							X

Clearly, the MNI/BIC and FSL toolkits are among the "most wanted."

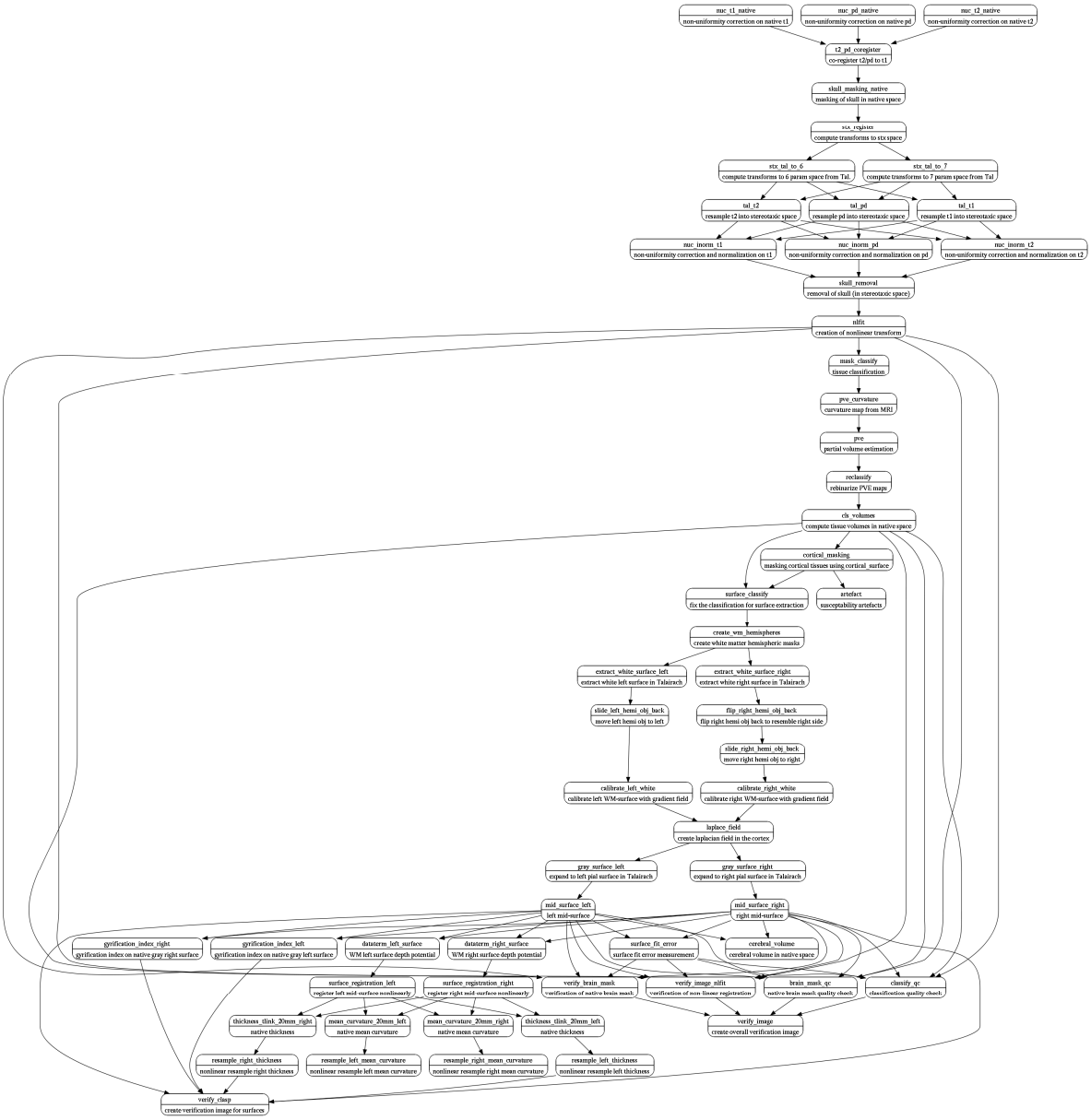
The following is a more detailed list of brain imaging tools and algorithms that will be available to end users through neuGRID. In this overview, the tools identified as "Tier 1" are necessary to run the cortical thickness extraction algorithm "CLASP" [8], which will be the primary test bed of the neuGRID infrastructure. Note that this document covers the *technical* availability of these

tools through neuGRID, but their actual use may still be restricted by licensing agreements, specifically for commercial applications (also the subject of D5.3).

Image Processing Tools

Tier 1 Image Processing Tools (MNI/BIC's MINC/CLASP)

The image processing pipeline (often referred to as "CIVET" [1,2]) used to estimate cortical thickness using the "CLASP" algorithm [8], developed at the Montreal Neurological Institute (MNI), is built on the MINC (Medical Image NetCDF) library [3] (also developed at MNI) which contains a large number of tools and algorithms ranging from generic to very specific for the brain imaging analyses. The following figure contains a high-level workflow diagram of the CIVET image processing pipeline (see also D10.1).



Note that the individual modules of this workflow:

artefact	brain_mask_qc	calibrate_left_white
calibrate_right_white	cerebral_volume	classify_qc
cls_volumes	cortical_masking	create_wm_hemispheres
dataterm_left_surface	dataterm_right_surface	extract_white_surface_left

extract_white_surface_right	flip_right_hemi_obj_back	gray_surface_left
gray_surface_right	gyrification_index_left	gyrification_index_right
laplace_field	mask_classify	mean_curvature_20mm_left
mean_curvature_20mm_right	mid_surface_left	mid_surface_right
nlfit	nuc_inorm_pd	nuc_inorm_t1
nuc_inorm_t2	nuc_pd_native	nuc_t1_native
nuc_t2_native	pve	pve_curvature
reclassify	resample_left_mean_curvature	resample_left_thickness
resample_right_mean_curvature	resample_right_thickness	skull_masking_native
skull_removal	slide_left_hemi_obj_back	slide_right_hemi_obj_back
stx_register	stx_tal_to_6	stx_tal_to_7
surface_classify	surface_fit_error	surface_registration_left
surface_registration_right	t2_pd_coregister	tal_pd
tal_t1	tal_t2	thickness_tlink_20mm_left
thickness_tlink_20mm_right	verify_brain_mask	verify_clasp
verify_image	verify_image_nlfit	

are by themselves already combinations of several more elementary operations from the MINC (Medical Image NetCDF) library [3], which contains the following libraries and utilities:

Name	**Description/purpose**
ILT	Image Layout Toolkit: a Perl module aimed at creating arrays of snapshot images out of MINC volumes
N3	Non-parametric, Non-uniform intensity Normalization: an algorithm to remove spatial intensity variations in brain images

arguments	Library for simple command line argument parsing for C++ programs
bicpl	A library containing about 50 command-line utilities for the manipulation of surface objects (Appendix A)
classify	A voxel classification tool able to run a number of different classification algorithms
conglomerate	A library of about 140 general purpose command-line tools for manipulating MINc volumes, tag files, and surface objects (Appendix B)
inormalize	A tool to perform slice-to-slice, volume-to-volume, or global intensity normalization
minc	The core MINC library, containing about 40 essential command-line tools for the generation and manipulation of MINC image volumes (Appendix C)
mincair	A registration package based on the AIR algorithm by Roger Woods [4]
mincblob	Computes the trace (volume increase or decrease - dilation) or translation (local volume changes that relate to movement of tissue not related to dilation) of a vector deformation field as produced by ANIMAL [5] non-linear registration.
mincdti	A utility for the analysis of Diffusion Tensor Imaging data
mincfft	A utility for performing Fast Fourier Transforms of MINC volumes
mincmorph	A utility for performing mathematical morphological operations in MINC volumes
mincregress	Performs regression operations on MINC files
mincsample	Utility to extract samples out of MINC files
mni_autoreg	MNI registration package containing utilities to perform both linear and non-linear spatial registration
mni_perllib	A general-purpose library of Perl functions necessary for several MINC utilities
mrisim	MRI simulation package

oobicpl	A library of 15 command line utilities for the manipulation of vertex statistics (Appendix D)
ray_trace	A utility to generate high-quality images of MINC volumes, surfaces, or combinations thereof
Volperf	MINC Bolus Delay Perfusion Map Calculation Package
Volregrid	MINC volume regridding package

Although a final triaging of these algorithms and tools still remains to be done, it is expected that the majority, if not all, of the tools and algorithms listed here will be made available to neuGRID end-users, as individual modules as well as in higher-level modules or workflows.

Tier 2

The following tools have been identified as desirable for use within neuGRID, but at the moment are considered secondary to the implementation of the Tier 1 toolkits. They include:

- fMRIB Software Library (FSL): BET, Flirt, Fnirt, FDT, FAST, Melodic (visualization tool), Siena, XSiena, FEAT, http://www.fmrib.ox.ac.uk
- MRIcro, http://www.sph.sc.edu/comd/rorden/mricro.html
- BioInformatics Research Network (BIRN) (Gradiant Non-Linearity Distortion Correction): Gradient non-linearity. http://www.nbirn.net/
- DRG Fluid.
- Brainvoyager http://www.brainvoyager.com/
- Matlab http://www.matlab.com
- Analysis fo Functional NeuroImages (AFNI), http://afni.nimh.nih.gov/afni/
- E-prime http://www.pstnet.com/
- Statistica
- LoNI http://www.loni.ucla.edu/Software/ tools
    - Dual_warpe_warpcurve, Decoder_blend_all, mk_seg16bit, mk_gray, add_gray_to_inflated_LEFT1, add_gray_to_inflated_RIGHT1, pmap_apeVSctrl, make_UVL_*; 1st_script_tracer_avg_DIAG; 2nd_script_core_test_L_DIAG; 2nd_script_core_test_R_DIAG; Pmap_DistCore_DIAG
- IdeALab Tools (IdeALab) http://neuroscience.ucdavis.edu/idealab/software/index.php
- Image conversion software
- 3D Slicer, VTK, Freesurfer, MPIAV, NA-MIC Kit components, MED-INRIA, BrainVoyager, BrainMAP

It should be noted that a number of these tools are standalone visualization tools or tools that are inextricably linked with an existing GUI (Graphical User Interface) which neuGRID, as a web- and grid-based service, will almost certainly not be able to provide. However, neuGRID will be able to (pre-) process imaging data that a user will be able to download and subsequently import into such tools.

Statistical Analysis Tools

The list of statistical analysis tools is considerably smaller and contains:

Tier 1 Statistical Analysis Tools (MNI/BIC's MINC/CLASP)

Name	**Description/Purpose**
glim-image	Part of the MINC toolkit; performs a variety of voxel-wise statistical tests on image data
R	Generic statistical analysis package [6]
RMINC	Interface between R and MINC, allowing the use of R for performing voxel- and vertex-wise statistical tests on MINC volumes [7]

Tier 2 Statistical Analysis Tools

- Statistical Parametric Mapping – SPM http://www.fil.ion.ucl.ac.uk/spm/software/
- Hermes (Hermes Medical) B-MAP (Pipeline 1 and Pipeline 2) http://www.hermesmedical.com/
- SPSS http://www.spss.com/
- Matlab, Quanta 6.1

Conclusions

Given the stated neuGRID goals, which in effect translate to "bringing the brain imaging centre home to the scientist", the neuGRID infrastructure will need to make a large number of brain imaging services available to its users. This library of brain image analysis functions spans the range of elemental operations such as image format conversion and arithmetic, through higher-level, domain-specific image processing tools such as those typically used for voxel classification, brain structure segmentation, cortical surface extraction, etc, to the statistical analysis packages necessary to analyze the processed image data.

A comprehensive list of the image processing tools that neuGRID aims to make available to its users has been presented in this deliverable. These tools were grouped into "Tier 1" and "Tier 2", where the Tier 1 set of tools are considered essential to meet neuGRID's goal of providing cortical thickness analyses using the CLASP algorithm, while the Tier 2 tools, although identified as desirable by user requirements elicitation, may not be implemented during the three years of the construction of the infrastructure. Note however, that another primary neuGRID goal is for the infrastructure to be modular, flexible and expandable with a low barrier of entry of new algorithms and tools. In other words, it is expected that the library of available tools will continue to grow, as neuGRID's users will develop and/or add new modules.

The list of tools and algorithms was derived to a large extent from the work performed in Workpackage 9 "User & System Requirements Analysis", and in close collaboration with all neuGRID partners, and specifically partners involved in Workpackage 6 (Distributed Medical Services, which will cover parts of the data anonymization and workflow management) and Workpackage 10 (Algorithms and Pipeline Gridification, which is concerned with allowing the tools to be executed in a grid infrastructure).

Given that some of the work that this deliverable relies on, specifically the User Requirements Analysis, is still ongoing, an update to this deliverable may be released in due course.

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Appendix A: "bicpl" library listing

add_surfaces	ascii_binary	average_objects
average_surfaces	bicobj2oogl	bicobj2vtk
check_polygons	colour_object	convert_object
copy_colours	create_grid	create_rectangle
create_tetra	diff_points	diff_surfaces
dump_curvatures	dump_point_diffs	dump_points
dump_polygons	dump_vertex_normal_diffs	half_polygons
make_colour_bar	make_concentric_surface	manifold_polygons
measure_surface_area	merge_polygons	objconcat
perturb_surface	polygon_map	polygons_to_lines
print_n_polygons	print_object_centroid	print_object_limits
reconstitute_points	refine_mesh	separate_polygons
set_line_width	set_object_colour	set_object_opacity
set_object_surfprop	smooth_lines	smooth_normals
spline_lines	split_polygons	subdivide_polygons
subdivide_values	triangulate_polygons	

Appendix B: "conglomerate" library listing

add_labels	apply_sphere_transform	autocrop_volume	average_voxels
blur_surface	box_filter_volume	box_filter_volume_nd	chamfer_volume
chop_tags	clamp_volume	classify_sulcus	clean_surface_labels
clip_tags	close_surface	cluster_volume	coalesce_lines
compare_left_right	compare_left_right_groups	compare_lengths	composite_images
composite_minc_images	composite_volumes	compute_bounding_view	compute_icbm_vols
compute_resels	concat_images	contour_slice	convex_hull
count_thresholded_volume	create_2d_sheet	create_2d_surface	create_box
create_four_volumes	create_label_map	create_landmark_full_volume	create_mahalanobis
create_surface_interpolation_lsq	create_warping_points	diff_mahalanobis	dilate_volume
dilate_volume_completely	dim_image	dump_deformation_distances	dump_points_to_tag_file
dump_rms	dump_transform	dump_uv	evaluate
extract_largest_line	extract_tag_slice	fill_sulci	find_buried_surface
find_image_bounding_box	find_peaks	find_surface_distances	find_tag_outliers
find_vertex	find_volume_centroid	fit_3d	fit_curve
fit_curve2	flatten_polygons	flatten_sheet	flatten_sheet3
flatten_to_sphere	flatten_to_sphere2	flip_tags	flip_volume

f_prob	gaussian_blur_peaks	get_tic	group_diff
histogram_volume	intensity_statistics	interpolate_tags	labels_to_rgb
label_sulci	lookup_labels	make_diff_volume	make_geodesic_volume
make_gradient_volume	make_grid_lines	make_line_links	make_slice
make_sphere_transform	make_surface_bitlist	map_colours_to_sphere	map_sheets
map_surface_to_sheet	marching_cubes	mask_values	mask_volume
match_tags	mincdefrag	mincmask	mincskel
minc_to_rgb	minctotag	mritotal_suppress	multispectral_stx_registration
nlfit_smr	normalize_pet	place_images	plane_polygon_intersect
preprocess_segmentation	print_2d_coords	print_all_label_bounding_boxes	print_all_labels
print_axis_angles	print_volume_value	print_world_value	print_world_values
random_warp	regional_thickness	remap_to_lobes	reparameterize_line
rgb_to_minc	scale_minc_image	scan_lines_to_polygons	scan_object_to_volume
segment_probabilities	smooth_mask	sphere_resample_obj	spherical_resample
stats_tag_file	subsample_volume	suppress_fat	surface_mask
surface_mask2	tags_to_spheres	tagtominc	tag_volume
threshold_volume	transform_objects	transform_tags	transform_volume
trimesh_resample	trimesh_set_points	trimesh_to_polygons	two_surface_resample
volume_object_evaluate			

Appendix C: "MINC" library listing

dcm2mnc	ecattominc	invert_raw_image
mincaverage	minccalc	mincconcat
mincconvert	minccopy	mincdiff
mincdump	mincedit	mincexpand
mincextract	mincgen	mincheader
minchistory	mincinfo	minclookup
mincmakescalar	mincmakevector	mincmath
minc_modify_header	mincpik	mincresample
mincreshape	mincstats	minctoecat
minctoraw	mincview	mincwindow
mnc2nii	nii2mnc	rawtominc
transformtags	upet2mnc	vff2mnc
voxeltoworld	worldtovoxel	xfmconcat
xfmflip	xfminvert	

Appendix D: "oobicpl" library listing

create_lines	obj_colour_to_texture	object_hemispheres
surface_area_roi	surface_probability_map	surface_volume_coordinates
vertstats_average	vertstats_colour_object	vertstats_extract
vertstats_find_peaks	vertstats_info	vertstats_math
vertstats_stats	vertstat_to_volume	white_cortex_validity